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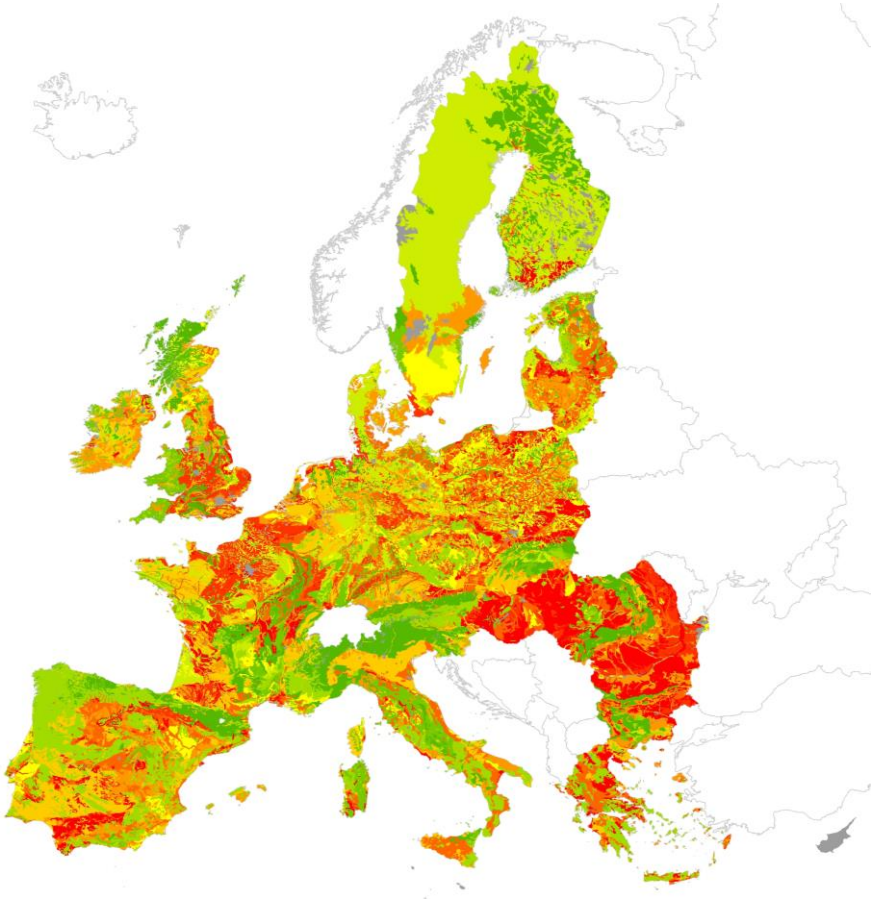

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Mapping the storing and filtering capacity of European soils

Authors

András Makó	Hungarian Academy of Sciences, Centre for Agricultural Research
Mihály Kocsis	University of Pannonia, Georgikon Faculty
Gyöngyi Barna	Hungarian Academy of Sciences, Centre for Agricultural Research
Gergely Tóth	European Commission, DG Joint Research Centre

Table of contents

Abstract

The purpose of the current study was to develop an estimation method based on available soil map information (categorical data) and thereafter estimate and map across Europe the soil filtering and storing capacity of different substances, which support ecosystem services and those which present a hazard to the ecosystem functioning. Pollutants were grouped as follows: (1) elements in *cationic form*; (2) elements in *anionic form*; (3) *solids and pathogenic microorganisms*; (4) *non-polar organic chemicals* and (5) *nonaqueous phase liquids* (NAPLs).

The spatial pattern of areas with high soil storing capacity are largely different depending on the stored substances. In general, those soils are characterized by good storing capability that have thick topsoil and subsoil layers and these layers are free from the effects of groundwater. As the content of clay and humus content increases and the stone or gravel content decreases, the storage capacity increases simultaneously. However, the effect of soil pH and the soil mineralogy is different depending on the various groups of pollutants (e.g. the calcareous soils with high swelling clay mineral content are able to bind more cations, whereas the acidic soils or the soils with high sesquioxide content have higher anion storing capacity).

The soil filtering capacity pattern of Europe in the case of different groups of substances are in part similar to the storing capacity pattern. The main difference between the two parameters was to take account of infiltration rate and the thickness of the filtration path up to the groundwater during the filtering capacity estimation.

1. Introduction

Soil supports ecosystem services by performing its function to filter and store substances and there is a requirement to increase awareness of the role of soil in preserving ecosystem services in Europe. Creating a map of the capacity for filtering and storing functions of different soils across the climatic conditions of Europe is one element of this action. In this first step, maps for the European Union were prepared, including area of its 25 Member States for which all data input was available (all EU Member States except Croatia, Cyprus and Malta).

The soil is a natural body. It has developed over a long time in a place through natural processes (weathering, humification, leaching etc.) under natural conditions (climate, organism, water, topography) from natural materials (parent materials). Soils however, continually change at different rates and along different pathways and are never stationary for more than a short periods of time. The changes are physical, chemical, and biological (biogeophysical, biogeochemical) and may and affect all soil phases. Despite these changes, the state of the soil always tends to remain at equilibrium with the environment it is exposed to. Thus, there are always complex interaction between the soil and environment [1–3].

When water, rain or wastewater falls on soil, some is evaporated and transpired, some runs off, and the most part infiltrates. Soil stores some water, but it is a leaky reservoir that loses water downward by seepage and upward by evaporation. Thus a considerable amount of water passes through the soil profile into the groundwater. During temporary storage and transmittance of this water in soil, the sediments may deposit in soil matrix, the possible suspended or dissolved contaminants may remove by reactions with soil constituents or exchange in the colloidal phase, and the purified water enters into the groundwater or into the surface waters. In a healthy soil ecosystem soil reduce the impacts of pollution by buffering, detoxifying, and decomposing potential. Quality of water in the watershed largely depends of the quality of soil around. So, soil acts as a natural filter medium, in which contaminants, pathogens and toxins that might otherwise foul the terrestrial environment are rendered harmless [4–6].

Modern society, however, generates ever greater quantities of potentially toxic materials and waste products, some of which do not occur naturally. Pollution is defined as the introduction of any substance to the environment that adversely affects the usefulness of a medium. Pollution and contamination are used mainly synonymously to mean the introduction into the environment by human of substances that are harmful or poisonous to people or ecosystems. Soil pollution is a global problem that threatens the life of microorganisms, plants, animals, and humans [7; 8].

Soil can filter pollutants (agrochemicals or other substances), whose properties and concentrations are potentially hazardous to the environment and/or human health. This filtering function of soil prevents hazardous materials from reaching groundwater. In the filtering process, substances are filtered out of percolation water and are bound by surfaces of solid phase (mainly by soil colloids: clay minerals, oxides, humic materials) in the soil. In the buffering process, which can be associated with the filtering, soil neutralizes acidifying impacts, thus preventing exposure of hazardous materials, eutrophication and a pH decrease. The extent to which substances can be deposited and bound is determined by soil *storing capacity*. Once the soil's *filtering and buffering capacity* is exceeded, the soil releases the stored pollutants, which end up in the groundwater or are uptaken by plants – and thus may enter the food chain [9; 10].

Soils vary greatly in their filtering, storing and buffering capacity. Under certain conditions, substances may take months or years to move from the land surface to the groundwater. In other cases, they can flow almost directly into the groundwater. The understanding of the interaction of soil characteristics (and related natural, e.g. climatic, hydrologic conditions) is essential in estimating the soil filtering, storing and buffering properties and determining the potential for groundwater (and connected surface waters) pollution in a given situation [11–14].

Soil pollution arises mainly from disposal of solid and liquid wastes in the ground; disposal of chemical wastes from the industries into the soil; indiscriminate use of agriculture chemicals, including fertilizers and pesticides; application sewage sludge and compost without judging metal or trace organic contamination; leakage of pipelines or

underground tanks into the soil; mining activity; irrigation with polluted water etc. Frequently, pollutants are introduced into the food chain via plants that have taken them up from soil or the atmosphere, and these pollutants often cause irreversible damage to individual organisms or to entire communities as a result of accumulation and exclusion processes. Therefore highest priority on the control of the influence on soil chemistry and microbial activities has to be given in the future [7; 15].

In recent decades interest has arisen in the possibilities and limitations of applying various waste materials to the land so as to utilize the soil's ability to filter, retain, buffer, immobilize, decompose, or otherwise mitigate the hazards of polluting agents. The soils have a significant but limited capacity to make harmless pollutants. The purification processes involved include physical transport phenomena, as well as complex chemical and microbiological interactions that take place primarily in the upper layer of soil [7].

The soil's ecological functions are among the others the substance storing, filtering, buffering and transformation capacity. These functions become increasingly important, because of the above mentioned increasing pollution effect. Soils may react through mechanical filtration, physical or chemical absorption and precipitation on its inner surfaces, or microbiological and biochemical mineralization and metabolization. As long as these filtering, storing, buffering and transformation capacities can be maintained, there is no danger to the groundwater or to the food chain. However, these capacities of soils are limited and vary according to specific soil and pollutant conditions [16].

The purpose of the current study is to assist with the implementation of the research programme on soil quality indicators, namely to facilitate the completion of a new soil quality indicator by supplying reliable spatial data on the soil's function to filter and store substances.

The objective of this study is to estimate and map the soil filtering and storing capacity of different substances across Europe.

Scope of the study includes the modelling and mapping of behaviour of those groups of substances which support ecosystem services (nutrients) and those which present a hazard to the ecosystem functioning (overused nutrients and pollutants). Literature review of this subject has shown that the following *problem substances* occur during the contamination of soil/subsurface/groundwater/surface water systems:

- Nutrients,
- Organics and Pesticides,
- Nonaqueous Phase Liquids (NAPLs),
- Pathogenic Microorganisms,
- Metals,
- Solids (Suspended and Dissolved).

Nutrients

Nitrogen- and phosphorus-containing compounds are often found in the water infiltrated into the soil. Farmers and homeowners apply fertilizers to the soil to promote plat growth. Nitrates result both from vehicular exhaust on the road and from fertilization of agricultural soil. Infiltrating and percolating water also contains phosphorus from motor oils, fertilizers, bird droppings, and animal remains [7; 8].

Organics and Pesticides

Although organics are also commonly found in infiltrating and percolating water of agricultural areas, runoff from *industrial areas* has been shown to contain higher concentrations of certain organics, such as pentachlorophenol, bis(2-ethylhexyl) phthalate or the polycyclic aromatic hydrocarbons.

Thousands of pesticide and pesticide formulations exists. They are classified on the basis of the organisms they attack (insecticides, herbicides, fungicides, nematocides, rodenticides etc.) and on the basis of the chemical structure (e.g. chlorinated hydrocarbons, organophosphates, carbamates etc.). The wide variation in chemical structure of pesticides results the wide variation in their behaviour in soil and groundwater [8; 17].

Nonaqueous Phase Liquids (NAPLs)

In general, water is the primary liquid in soil. However, NAPLs released during spills, leaks, and tank or pipe ruptures may enter soil and replace water. The basic principles governing the migration of water in soil are generally the same ones governing of NAPLs. NAPLs are generally not miscible with water, therefore their distribution in soil in presence of water should be addressed. The term of NAPLs is used to refer to unrefined crude oil, refined petroleum (e.g. gasoline, kerosene), and petrochemicals (e.g. TCA, TCE) [8; 18; 19].

Pathogenic Microorganisms

Urban, agricultural or industrial runoff has been found to contain different pathogens. These pathogens include, but are not limited to, *Salmonella*, *Pseudomonas aeruginosa, Shigella, or enteroviruses*. *Shigella* species causing bacillary dysentery are one of the primary human-enteric-disease-producing bacteria present in water. *Pseudomonas* is reported to be the most abundant pathogenic bacteria organism in urban runoff and streams. Pathogenic *E. coli* can also be commonly found in urban runoff. *Viruses* also may be important pathogens, very small viral concentrations are capable of producing infections or diseases, especially when compared to the large numbers of bacteria organisms required for infection.

Infiltration will increase bacterial and viral penetration into the soil profile. Like the organics, the greatest chance for contamination occurs when the distance to the groundwater is small. Most, but not all, pathogens are usually filtered out or inactivated during percolation through the soil [20].

Metals

The heavy metals of most concern in infiltrating and percolating water are lead, zinc, copper, nickel, and chromium. Most of these heavy metals have very low solubilities at the typical pH of receiving waters. They either are removed by sediment adsorption or are organically complexed with other particulates and are easily removed during filtration. Metals in urban runoff originate both at industrial sites and on highways, etc., as part of the exhaust and other residue left by vehicular use. Metals seem to be more prevalent in runoff from industrial areas, although they are also commonly found in infiltrating and percolating water of agricultural areas [8; 21].

Solids

Suspended solids are of concern in runoff because of their ability to clog infiltration areas. During percolation, the suspended and colloidal particles that were not stopped at the surface travel downward until they are trapped by pores that are smaller than they are. Fine to medium textured soils remove essentially all of the suspended solids by straining, while coarse textured soils allow deeper penetration of these particles. *Dissolved solids* are in urban runoff due to the use of salt to de-ice roads in the winter and due to fertilizer and pesticide salts from the use of those items [10].

The relative magnitude of the filtering and storing capacity may vary considerably, based on a number of factors (Fig. 1). *Climate* (quantity, form and distribution of precipitation, temperature etc.), *topography*, *plant cover* and *land use* have been identified as important factors affecting infiltration and runoff. *Impervious surfaces*, such as compacted soil layers or roads, reduce infiltration of rainfall into the ground [8].

Filtration can be defined as an interaction between the solution (or suspension) and the filtering soil material. Pollutants are removed from the solution when they become attached to the media or to previously captured particles. In general, the *key properties* of the soils are *infiltration and percolation rate; liquid phase retention capacity; surface area (surface-substances interactions: physical straining ability, adsorption/ion-exchange ability); aerobic/anaerobic condition; soil depth to the groundwater and the different (chemical and/or microbiological, biological) transformation processes*. The most important physical and chemical soil parameters that influence the above properties are *soil texture*

(clay content), *gravel or rock* content, *soil mineralogy* (especially type of clay minerals and oxides/hydrous oxides), *organic matter content and pH.* Due the lack of information about these properties or parameters there are often necessary to estimate them. Knowing the *soil types*, the topography or the geological origin there is possible to assess some missing information [22; 23].

The *liquid phase properties* can also affect the filtration and storing capacity. The most important properties are *polarity, viscosity, density* and the *type* and *concentration of substances* in liquid phase. Density and viscosity are both temperature dependent, and density will also depend upon the concentration of dissolved solids in the water [18; 19].

The above aspects of filtering and storing will be modelled. *Figure 1* summarises the most relevant soil processes, properties and natural conditions which are the factors of the soil filtration and storing capacity.

However, this study will not assess the effect of (chemical, biological and microbiological) *transformation* processes on the substances filtrating and storing capacity of the soils.

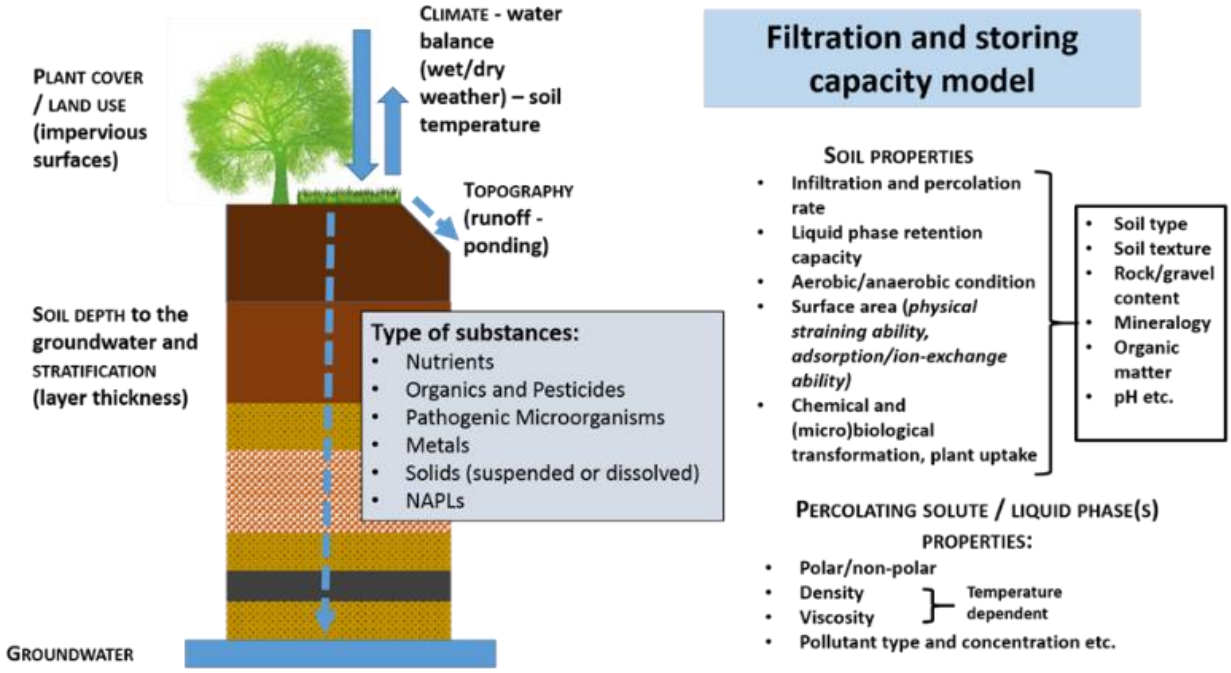

Figure 1. The proposed filtration and storing capacity model

2. Working approach and methodology

The geographical extent of the study includes 27 Member States of the European Union (EU). Data availability is one of the most important factors to estimate the planned soil function parameters. As far as the input data in soil maps, databases and related land use, climate etc. information are available and accurate, so can be used the developed estimation methods. To estimate the filtering and storing capacity the following European databases were available and usable as input data:

- *The European Soil Database v.2.0* [24]*;*
- *Pedotransfer Rules database* (PTRDB) [25];
- *CORINE LC* database to obtain land use/cover data [26];
- *Climate data* (agro-climatic zones, grouped agro-climatic areas) [27].

The European Soil Database did not contain all soil properties that affect the substances filtering and storing capacity. Using the existing pedotransfer rules of the Pedotransfer Rules database and based on expert estimates the missing soil parameters (e.g. infiltration and percolation rate, soil mineralogy etc.) were calculated.

The steps of the estimation and mapping procedure associated with the soil storing and filtering capacity were as follow: in the first step the major groups of substances and the associated most relevant natural and soil properties were identified, together with their effects on filtering and storing capacity. In the next step of the capacity assessments an evaluation algorithm was created for each substances groups (identifying ranges of values of relevant soil properties and natural conditions and estimating the potential of soil types to substance filtering and storing). Finally, filtering and storing capacity maps of European soils were created for each substances groups.

2.1 Identifying the groups of substances

In the introduction the problem substances (occur during the contamination of soil/subsurface/groundwater/surface water systems) were summarised as follows: nutrients, organics and pesticides, nonaqueous phase liquids (NAPLs), pathogenic microorganisms, metals and solids. However, within these groups occur materials with different properties. Nutrients in anionic (phosphate or nitrate ions) and cationic (potassium ion) form behave quite differently in soils. Heavy metals also behave differently depending on the charging conditions. But the organics and pesticides form also a heterogeneous group, since they can also have a positive or negative charge or may be also non-polar. However, microbes and solid pollutants are similar in terms of soil storing and filtrating capacity. Therefore, the pollutants were regrouped:

(1) elements in *cationic form* (e.g. K^+, Na^+, Ca^{2+}, Fe^{2+}, Fe^{3+} or heavy metals, as Ba^{2+}, Cd^{2+}) and organic chemicals with positive charges (e.g. organoamines, metallo-organics);
(2) elements in *anionic form* (e.g. nutrients, as phosphate, nitrate; heavy metals, as molybdate, arsenate or other elements, as borate, sulfate, halides) and organic chemicals with negative charges (e.g. organic chemicals possess hydroxyl or carboxyl functional groups);
(3) *solids and pathogenic microorganisms*;
(4) *non-polar organic chemicals* and
(5) *nonaqueous phase liquids* (NAPLs).

2.2 The clay content of the soil profile

The storing and filtering capacity of soils were estimated for the average 1.5 m depth soil profile. There were two exceptions to this rule: (1) the solid rock – as parent material – within 1.5 m and (2) water saturated soil layer within 1.5 m. (The solid rock is unable to perform the storing and filtering functions, because it does not pass through the infiltrating soil solution and the water saturated soil layer is continuously leached due to the groundwater which prevents the storage and filter properties of the soils.) Therefore firstly

the "effective soil depth" was estimated, i.e. the *maximum depth of the soil profile with storage and filter properties (MDSP)*.

Based on the above, it depends on the depth to the impermeable solid rock (DISR) and the depth to the groundwater (DG). DISR can be estimated on the basis of the soil parent material (PARMADO and PARMASE) and the depth to rock (DR) [28]. DG is predictable according to the soil classification (Full soil code of the soil taxonomy unit (STU) from the World Reference Base (WRB) for Soil Resources: WRBFU [29].

It was supposed, that the soil storing and filtering properties are generally dependent on the soil clay and humus content (mostly they represent the soil colloids) [7]. As a first step therefore the clay content of the soil profile (SPCC) was estimated. Prior to this, however, some auxiliary parameters had to be determined. Because of the soil profile can contain soil layers with different soil texture, we needed information about the stratification. The modified depth to a textural change code (MTDCH) shows the estimated depth where occurs a textural change between the topsoil and subsoil. The MTDCH can be determined according to the textural change information of ESDB (TEXTDEPCHG) and the "effective soil depth" (MDSP). (The textural change is taken into account in the case where MDSP was deeper as TEXTDEPCHG. Otherwise, the textural change was not considered.)

The *clay percentage of the topsoil (CPT) and subsoil (CPS)* were estimated on the basis of the dominant and secondary surface textural class of the STU (TEXTSRFDOM and TEXTSRFSEC) or on the basis of the dominant and secondary sub-surface textural class of the STU (TEXTSUBDOM and TEXTSUBSEC) [4]. In the case when the TEXTSRFDOM and TEXTSRFSEC or TEXTSUBDOM and TEXTSUBSEC did not match, weighted average code was calculated. If the secondary surface or sub-surface textural class of the STU was peat, it was not considered.

The modified clay percentage of the topsoil (MCPT) and subsoil (MCPS) was estimated from the CPT and CPS, the volume of stones (VS) and the topsoil or subsoil packing density (PD_TOP or PD_SUB). (The higher is the stone content and the lower is the packing density, the more reduced the relative clay amount per unit soil volume.) It was assumed that VS is unchanged throughout the soil profile [4; 7]. Finally, the ***clay content of the soil profile (SPCC)*** was estimated on the basis of the MCPT, MCPS, MTDCH and MDSP.

2.3 Humus content of the soil profile and the humus quality

In the next step the ***humus content of the soil profile (SPHC)*** was estimated. To do this, we had to determine previously the *thickness of the humus layer (HLT)*. This parameter was estimated on the basis of soil classification (WRB_GRP: Soil reference group code of the STU from the World Reference Base (WRB) for Soil Resources [29]. If the "effective soil depth" (MDSP) was lower than the characteristic humus layer thickness of a WRP group, the latter overwrote the HLT category code.

To estimate the humus content of the soil profile (SPHC) the following information of the ESDB were used: (1) OC_TOP = topsoil organic carbon content, (2) PEAT= peat, (3) VS = volume of stones and (4) PD_TOP = topsoil packing density. The clay percentage of the topsoil (CPT) and subsoil (CPS) provided additional information about the peaty layers of the soil profile. In case of peat soils or peaty soil layers high humus content were assumed. In other cases the humus content was estimated from the topsoil organic carbon content (OC_TOP).

The VS and the PD_TOP might alter the humus content: the higher is the stone content and the lower is the packing density, the more reduced the relative humus content per unit soil volume. (It was also assumed that VS is unchanged throughout the soil profile.) Finally, the SPHC code was estimated taking into account the HLT [7; 30]. The storing and filtering properties of soil humus content is highly dependent on the ***humus quality (HQ)***. The quality of the humic substances of the soils is predictable on the basis of soil taxonomy (WRB_GRP). There were distinguished three categories: soils containing predominantly (1) fulvic acids (2) humic acids and (3) peaty, partially decomposed materials [7; 30].

2.4 Estimating the environmental factors

The storing and filtration capacity of soil depends on different **environmental factors**, such as climate and topography. The *water balance (WB) of the soil profile* is predictable on the basis of the average annual rainfall and temperature [4]. To perform this prediction the data of regrouped climatic zones of Europe [31] were applied. (The authors created these zones for continental scale soil quality assessment using the original 35 climatic areas of [27]). To evaluate the effects of slope conditions on the infiltration the *modified slope categories of the STUs (SLOPEM)* were first estimated. The weighted average was calculated from the SLOPE-DOM (Dominant slope class of the STU) and SLOPE-SEC (Secondary Slope class of the STU), considering twofold the dominant slope parameter.

Thereafter the *modified water balance code (WBM)* was estimated according to the WB, SLOPEM and the code for the grouped CORINE 2006 categories (CORGRP_CAT). Less water infiltration was assumed, if the slope is steeper and/or the soil is uncovered part of the year (arable and horticultural land use) [4; 32].

In the next step the ***estimated leaching factor (LEACH_f)*** was calculated from WBM. (The smaller the WBM code is, the higher the LEACH_f value, and vice versa.) To ascertain the filtration capacity of the soils the *water infiltration rate (IR)* is a decisive soil parameter [4; 6; 32]. To determine the soil IR code, first some auxiliary factors were estimated. *Topsoil (TPD_f) and subsoil (SPD_f) packing density factors* are dependent on PD_TOP and PD_SUB. The values of these factors are higher, if the packing density is low, and vice versa. Because of the infiltration is less affected by the subsoil compaction, the rate of change is less for the SPD_f.

The *impermeable layer factor (IL_f)* is dependent on the code for the presence of an impermeable layer within the soil profile of the STU (IL). The value of IL_f is higher (1) if no impermeable layer exists and the smaller, the closer is the impermeable layer to the ground surface.

Using the above parameters and the SPCC the IR was estimated. The infiltration rate is usually higher in sandy soils and lower in clayey soils, but this may change due to compaction or impermeable layer proximity. 10 grade ***infiltration rate factor (IR_f)*** was estimated according to the IR code. The ***groundwater depth factor (DG_f)*** was calculated from the estimated depth to the groundwater (DG) to take into account the depth to the groundwater during the filtration capacity estimation.

2.5 Estimating the cation exchange capacity and specific surface area of soils

The storing and filtration capacity of soil depends on the clay mineral and the organic matter surfaces and also on the charge of surfaces [4; 7; 33; 34]. The fixation and adsorption processes are dependent on the pH value or base saturation and on the aeration (redox potential) of the soil layers. The total amount of cations adsorbed by the negative charges of clay minerals and humus materials on a unit mass of soil is defined as the cation exchange capacity (CEC) of the soil. According to the literature [35–38], the average CEC values of soil can be estimated from the clay content, clay mineralogy, organic matter content and organic matter (humus) quality [7].

The *cation exchange capacity related to the humus content (CEC_HUM)* was estimated from the SPHC and HQ. The average CEC of fulvic acid, humic acid and peat materials were 1000, 500 and 150 cmol(+)/kg, respectively. The *cation exchange capacity related to the soil minerals (CEC_MIN)* was estimated from the SPCC and the topsoil and subsoil mineralogy (MIN_TOP and MIN_SUB). The average CEC of KX (1/1 Min. + Oxy. & Hydroxy.), KQ (Minerals + Quartz), MK (2/1 & 1/1 Minerals), M (2/1 & 2/1/1 non swel. Min.), NA (Not applicable), TO (Andic Minerals), TV (Vitric Minerals) and MS (Swel. & non swel. 2/1 Min.) were 7, 9, 17, 25, 25, 25, 25 and 83 cmol(+)/kg, respectively.

The ***cation exchange capacity related to soil minerals and humus content (CEC_SUM)*** is the simple average of the CEC_HUM and CEC_MIN codes. The calculated

values were converted to a 10-point scale, where the code 1 represents the lowest and the code 10 the highest CEC values.

One of the key soil properties affecting the ability of the storing and filtering is the specific surface area (SSA). SSA is highly correlated with the soil's physical and chemical properties, such as different adsorption processes. The average SSA values of the soil can be estimated from the clay content, clay mineralogy, organic matter content and organic matter (humus) quality, based on the relevant literature [7; 30; 39].

The *specific surface area related to the humus content (SSA_HUM)* was estimated from the SPHC and HQ. The average SSA of fulvic acid, humic acid and peat materials were 5000, 2000 and 1000 m^2/kg, respectively. The *specific surface area related to the soil minerals (SSA_MIN)* was estimated from the SPCC) and the MIN_TOP and MIN_SUB. The average SSA of KX (1/1 Min. + Oxy. & Hydroxy.), KQ (Minerals + Quartz), MK (2/1 & 1/1 Minerals), M (2/1 & 2/1/1 non swel. Min.), NA (Not applicable), TO (Andic Minerals), TV (Vitric Minerals) and MS (Swel. & non swel. 2/1 Min.) were 32, 15, 74, 83, 83, 700, 700 and 416 m^2/kg, respectively. The ***specific surface area related to soil minerals and humus content (SSA_SUM)*** is the simple average of the SSA_HUM and SSA_MIN codes. The calculated values were converted to a 10-point scale, where the code 1 represents the lowest and the code 10 the highest SSA values.

2.6 Calculating the sorption factors

The *base saturation of the soil profile (BASE_SAT)* was estimated from the base saturation ESDB code of the topsoil and subsoil (BS_TOP and BS_SUB). Because there is no other information about the acidity of the soils, the soil pH was evaluated according to this parameter. Base saturation generally increases with an increase in soil pH (low BASE_SAT code means soils with low soil pH, and vice versa) [40–42].

The *aeration code (AER)* was used to describe the aerobic/anaerobic conditions (redox status) of the soils. It refers to the presence or absence of electrons in soil. The fixation of elements in soil is dependent upon the redox and pH status of the soil system. E.g. acidic (low base saturation code) and relative anaerobic (low AER code) soil condition means that most elements in cationic form do not exhibit a propensity to exist in immobile hydroxide, oxide, oxyhydroxide forms, they prefer to exist in mobile, dissolved forms. Therefore using the BASE_SAT and AER codes we are able to qualitatively estimate the fixation potential of the elements or chemicals with different charges.

The *cation sorption factor (**CATS_f**)* was estimated from the **BASE_SAT** and **AER** codes. The total concentration of substances (elements or chemicals) in soils consists of three parts:

(1) concentration of fixed substances comprising part of the structure of solid phase
(2) concentration of substances adsorbed onto the surface of soil minerals and onto organic matter and
(3) concentration of substances in soil water or groundwater [8].

The separation of the fixation and adsorption in soil-water system is not an easy task if we have few information about the soil condition, therefore we used the "sorption" term, which includes both soil processes [7]. (The concentration of substances solved in water phase and retained in soil capillary pores only indirectly, as the clay content dependent property was considered.) The cation sorption factor (**CATS_f**) simplifies the complex soil mechanisms. It was assumed that the sorption of elements in cationic form (and organic chemicals with positive charges) are higher at high base saturation (**BASE_SAT**) and at aerobic condition (**AER**) [43]. The calculated values were converted to a 10-point scale, where the factor 0.1 the worst and the code 1.0 the optimum cation adsorption conditions represents.

The *anion sorption factor (**ANS_f**)* was estimated also from the **BASE_SAT** and **AER** codes. There are different types of surfaces responsible for accumulating anions in soil. The most important are the oxides, the edges of alumino-silicate clay minerals (especially the 1:1 clay minerals) and the soil organic materials. The net positive charge of these

materials is highly dependent on the soil pH. If the pH is low, then will develop a positive surface charge. However, the fixation processes of substances in anionic form depends on the aerobic/anaerobic condition of the soil system, too [7; 44]. Therefore the anion sorption factor (**ANS_f**) simplifies the complex soil mechanisms as follows: the sorption of elements in anionic form (and organic chemicals with negative charges) are higher at low base saturation (**BASE_SAT**) and at aerobic condition (**AER**). The calculated values were converted to a 10-point scale, where the factor 0.1 the worst and the factor 1.0 the optimum anion adsorption conditions represents.

The *mineral factor (**MIN_f**)* was calculated from the topsoil and subsoil mineralogy (**MIN_TOP** and **MIN_SUB**) to take into account the oxide surfaces during the anion sorption estimation.

2.7 Storing and filtration capacity codes

The storing and filtering capacity codes were estimated based on the above derived parameters. The calculated values were converted to a 10-point scale, where the code 1 the lowest and the code 10 the highest capacities represents. To transform the estimated values (continuous scale variables) into limited number (10) of distinct categories the Visual Binning method was used (SPSS, Transform, Visual Binning, Equal Percentiles Based on Scanned Cases). This method generates binned categories with an equal number of cases in each bin using the empirical (empirical distribution function with averaging) algorithm for percentiles.

2.7.1 The cation storing capacity

The *cation storing capacity (**STOR_CAPCA**)* was estimated from the soil mineral cation exchange capacity (**CEC_MIN**), cation exchange capacity related to humus content (**CEC_HUM),** cation sorption factor (**CATS_f**) and leaching factor (**LEACH_f**). It represents the soil storing capacity for elements in cationic form (e.g. K^+, Na^+, Ca^{2+}, Fe^{2+}, Fe^{3+} or heavy metals, as Ba^{2+}, Cd^{2+}) and organic chemicals with positive charges (e.g. organoamines, metallo-organics). It was assumed that **CEC_HUM** is pH dependent, but only part of the **CEC_MIN** depends on soil pH (base saturation). The adsorption was calculated accordingly. The fixation of these materials however, is dependent on the soil pH (base saturation) and aerobity (e.g. the Fe^{2+} or FeS are mobile forms and Fe^{3+} or $Fe(OH)_3$, $Fe(CO_3)$ are immobile forms of iron) (**CAT_f**). The higher the leaching (**LEACH_f**), the less the storing capacity of the soils is.

2.7.2 The cation filtering capacity

The *cation filtering capacity (**FILT_CAPCA**)* was estimated from the soil mineral cation exchange capacity (**CEC_MIN**), cation exchange capacity related to humus content (**CEC_HUM**), cation sorption factor (**CATS_f**), infiltration rate factor (**IR_f**) and groundwater depth factor (**DG_f**). It represents the soil filtration capacity for elements in cationic form and organic chemicals with positive charges. It was assumed that the higher the cation sorption capacity of the soil (dependent on **CEC_MIN**, **CEC_HUM** and **CAT_f**), the higher the soil cation filtration capacity is. But this parameter also depends on the infiltration rate (**IR_f**): soils with high water infiltration rate, are assigned a low filtering capacity (no time enough for the physicochemical processes), and less permeable soils, with low infiltration rate, are assigned a high capacity. The filtration capacity of a soil indicates however, its capacity to bind substances in the soil and not let them reach the groundwater. The thickness of the filtration path up to the groundwater was considered also under this method (**DG_f**).

2.7.3 The anion storing capacity

The *anion storing capacity (**STOR_CAPAN**)* was estimated from the specific surface area related to soil minerals (**SSA_MIN**), mineral factor (**MIN_f**), specific surface area related to humus content (**SSA_HUM**), anion sorption factor (**ANS_f**) and leaching factor (**LEACH_f**). It represents the soil storing capacity for elements in anionic form (e.g. nutrients, as phosphate, nitrate; heavy metals, as molybdate, arsenate or other elements, as borate, sulfate, halides) and organic chemicals with negative charges (e.g. organic chemicals possess hydroxyl or carboxyl functional groups). It was assumed that the higher the specific surface of soil, the higher the possibility of the appearance of positive charges. The formation of positive charges at humic materials (**SSA_HUM**) is pH dependent, but only part of the mineral surfaces (**SSA_MIN**) have pH (base saturation) dependent positive charges. It was taken into account that sesquioxides have particularly large amount of positive charges (**MIN_f**). The anion adsorption was calculated accordingly. The fixation of these materials however, is dependent on the soil pH (base saturation) and aerobity (e.g. the mobility of Cr^{3+}, $HCrO_4^-$, CrO_4^{2-}, Cr_2O_3 and $Cr(OH)_3$ forms of chrome are different) (**ANS_f**). The higher the leaching (**LEACH_f**), the less the anion storing capacity of the soils is [45].

2.7.4 The anion filtering capacity

The *anion filtering capacity (**FILT_CAPAN**)* was estimated from the specific surface area related to soil minerals (**SSA_MIN**), mineral factor (**MIN_f**), specific surface area related to humus content (**SSA_HUM**), anion sorption factor (**ANS_f**), infiltration rate factor (**IR_f**) and groundwater depth factor (**DG_f**). It represents the soil filtration capacity for elements in anionic form and organic chemicals with negative charges. It was assumed that the higher the anion sorption capacity of the soil (dependent on **SSA_MIN**, **SSA_HUM** and **ANS_f**), the higher the soil anion filtration capacity is. The filtering capacity dependency on the infiltration rate (**IR_f**) and groundwater depth (**DG_f**) was taken into account similarly as in the case of cation filtering capacity.

2.7.5 The solids and pathogenic microorganisms storing capacity

The *solids and pathogenic microorganisms storing capacity (**STOR_CAPSO**)* was estimated from the specific surface area related to soil minerals and humus content (**SSA_SUM**) and leaching factor (**LEACH_f**). It was assumed that the sorption of different solid materials and microorganisms is dependent mainly on the soil surfaces (**SSA_SUM**). The higher the leaching (**LEACH_f**), the less the solids and pathogenic microorganisms storing capacity of the soils is.

2.7.6 The solids and pathogenic microorganisms filtering capacity

The *solids and pathogenic microorganisms filtering capacity (**FILT_CAPSO**)* was estimated from the specific surface area related to soil minerals and humus content (**SSA_SUM**), infiltration rate factor (**IR_f**) and groundwater depth factor (**DG_f**). It was assumed that the higher the solids and pathogenic microorganisms sorption in the soil (dependent on **SSA_SUM**), the higher the soil solids and pathogenic microorganisms filtration capacity is [10; 46–48]. The filtering capacity dependency on the groundwater depth (**DG_f**) was taken into account similarly as in the case of cation filtering capacity. But the estimated effect of the infiltration rate is opposite. In this case the suspended dirt and pollutant particles are mechanically fixed to the soil. (The term Mechanical Filtering Capacity means capacity of the soil to mechanically clarify a suspension [49]).

The filtering capacity of a soil was characterized by the amount of water being able to pass the respective soil in a given time unit [50]. The higher the filtering capacity is, the more water can pass. So if the residence time of the water is shorter, the higher the filtering capacity is. It means that soils with a high infiltration rate (**IR_f**) have a high solids and pathogenic microorganisms filtering capacity [10; 51].

2.7.7 The non-polar organic chemicals storing capacity

The *non-polar organic chemicals storing capacity (**STOR_CAPNP**)* was estimated from the specific surface area related to soil minerals and humus content (**SSA_SUM**) and leaching factor (**LEACH_f**). It was assumed that the sorption of different non-polar organic chemicals is dependent mainly on hydrophobic surfaces. The bigger soil surfaces (**SSA_SUM**), the higher the hydrophobic part of these surfaces is [8]. The higher the leaching (**LEACH_f**), the less the non-polar organic chemicals storing capacity of the soils is.

2.7.8 The non-polar organic chemicals filtering capacity

The *non-polar organic chemicals filtering capacity (**FILT_CAPNP**)* was estimated from the specific surface area related to soil minerals and humus content (**SSA_SUM**), infiltration rate factor (**IR_f**) and groundwater depth factor (**DG_f**). It was assumed that the higher the non-polar organic chemicals sorption in the soil (dependent on **SSA_SUM**), the higher the non-polar organic chemicals filtration capacity is. The filtering capacity dependency on the infiltration rate (**IR_f**) and groundwater depth (**DG_f**) was taken into account similarly as in the case of cation filtering capacity [52; 53].

2.7.9 The nonaqueous phase liquids (NAPLs) storing capacity

The *nonaqueous phase liquids (NAPLs) storing capacity (**STOR_NAPL**)* was estimated from the clay content of the soil profile (**SPCC**), specific surface area related to soil minerals and humus content (**SSA_SUM**) and leaching factor (**LEACH_f**). According to the literature (e.g. [18; 54–58] the sorbed and retained nonaqueous phase liquids amount depends on the pore size distribution (it is dependent on **SPCC**) and on the area of hydrophobic surfaces (it is dependent on the **SSA_SUM**) of the soils. The higher the leaching (**LEACH_f**), the less the nonaqueous phase liquids storing capacity of the soils is.

2.7.10 The nonaqueous phase liquids (NAPLs) filtering capacity

The *nonaqueous phase liquids (NAPLs) filtering capacity (**FILT_NAPL**)* was estimated from the specific surface area related to soil minerals and humus content (**SSA_SUM**), infiltration rate factor (**IR_f**) and groundwater depth factor (**DG_f**). It was quite difficult to define the NAPLs filtering capacity. This parameter was measured as the capacity of soils to clarify the infiltrating water contains dissolved and emulsified NAPL components. It was assumed that the higher the nonaqueous phase liquids component (mainly non-polar organics) sorption in the soil (dependent on **SSA_SUM**), the higher the NAPLs filtration capacity is. The filtering capacity dependency on the infiltration rate (**IR_f**) and groundwater depth (**DG_f**) was taken into account similarly as in the case of cation filtering capacity [59; 60].

The flow chart of the storing and filtering capacity estimation procedure is presented by the *Figure 2.*

The GIS tasks were performed with the software ESRI ArcGIS 9.3. The capacity codes of all the ESDB polygons were calculated using the key variables soil mapping units (SMUs) and soil taxonomy units (STUs). Then we mapped the storing and filtration capacity of substances for the SMUs across the European Union after assigning colors to a continuous scale of grade 10 capacity code system, where 1 represents the lowest and the code 10 the highest capacities. Thereafter we calculated the percentage area (PA) of each categories across the European Union and within each Biogeographical Region (BGR). A weighted capacity index (WCI) was calculated by the following formula:

$$\text{WCI} = \sum_{i=1}^{10} PA_i \times C_i,$$

where C_i was the capacity code and PA_i the percentage area of the *i*th category within the given BGR. The WCI values were normalized to ten-stage scale (WCI_{norm}).

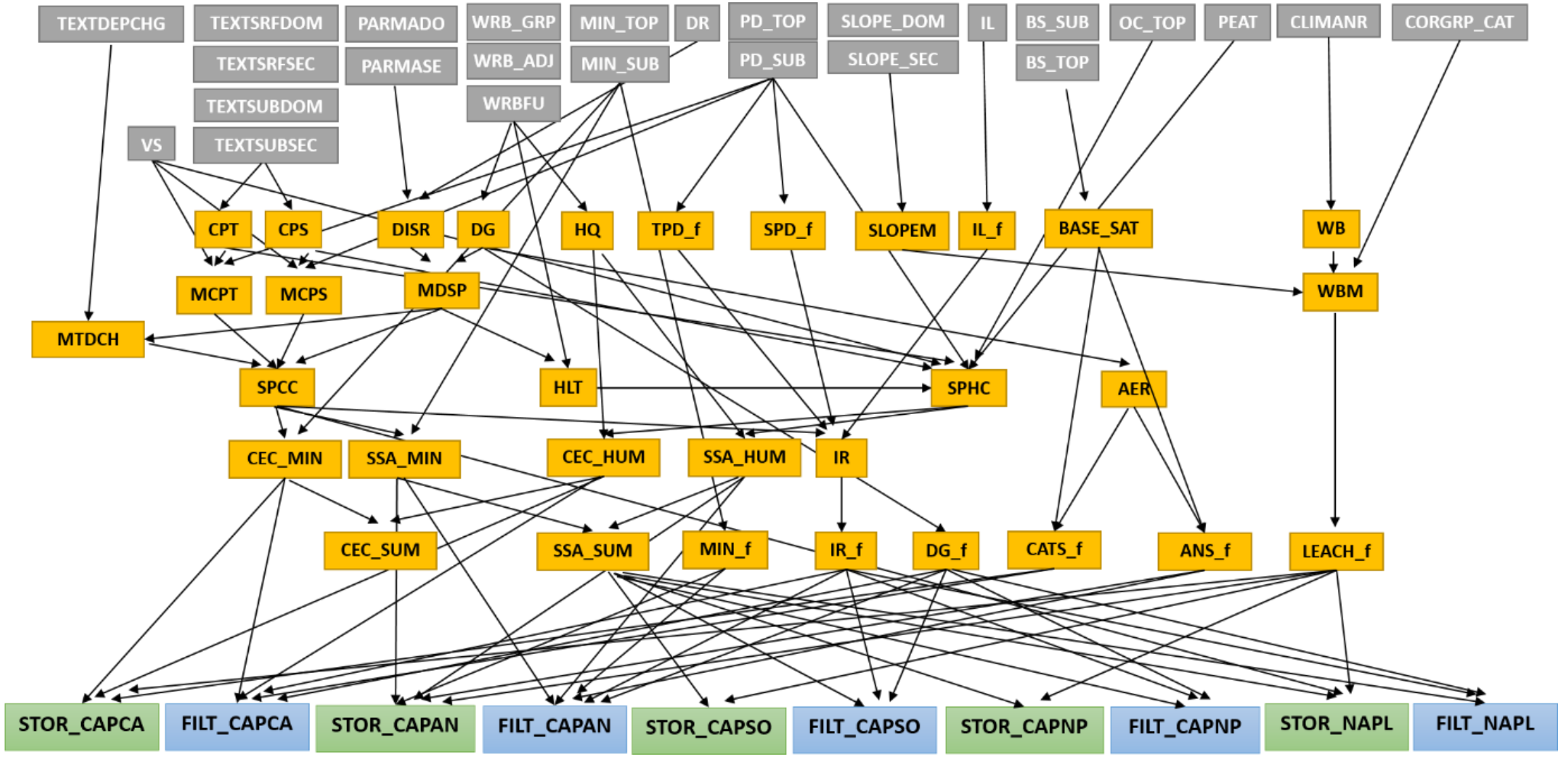

Figure 2. Diagram for the evaluation of the soil storing and filtering functions

3. Presenting the soil storing and filtering capacity maps

Results of soil storing and filtration capacity evaluation for fields of the European Union, prepared according to the above algorithm are presented in Fig. 3–12.

The spatial pattern of areas with high soil storing capacity (Fig. 3–7) are largely different depending on the stored substances. In general, those soils are characterized by good storing capability that have thick topsoil and subsoil layers and these layers are free from the effects of groundwater. As the content of clay and humus content increases and the stone or gravel content decreases, the storage capacity increases simultaneously. However, the effect of soil pH and the soil mineralogy is different depending on the various groups of pollutants (e.g. the calcareous soils with high swelling clay mineral content are able to bind more cations, whereas the acidic soils or the soils with high sesquioxide content have higher anion storing capacity).

The soil filtering capacity maps (Fig. 8–12) of different groups of substances are in part similar to the storing capacity maps, since both are based on the estimated CEC or SSA of soils. The main difference between the two mapped parameters was to take account of infiltration rate (IR_f) and the thickness of the filtration path up to the groundwater (DG_f) during the filtering capacity estimation. Moreover assessing the impact of infiltration rate depending on the quality of the infiltrating material were different (generally the filtering capacity increased in less permeable soils, but in the case of the solids and pathogenic microorganisms the estimated effect of the infiltration rate was opposite). These factors influenced primarily the spatial pattern of filtering capacity maps of substances in anionic forms, the NAPLs and most significantly the solids and pathogenic microorganisms.

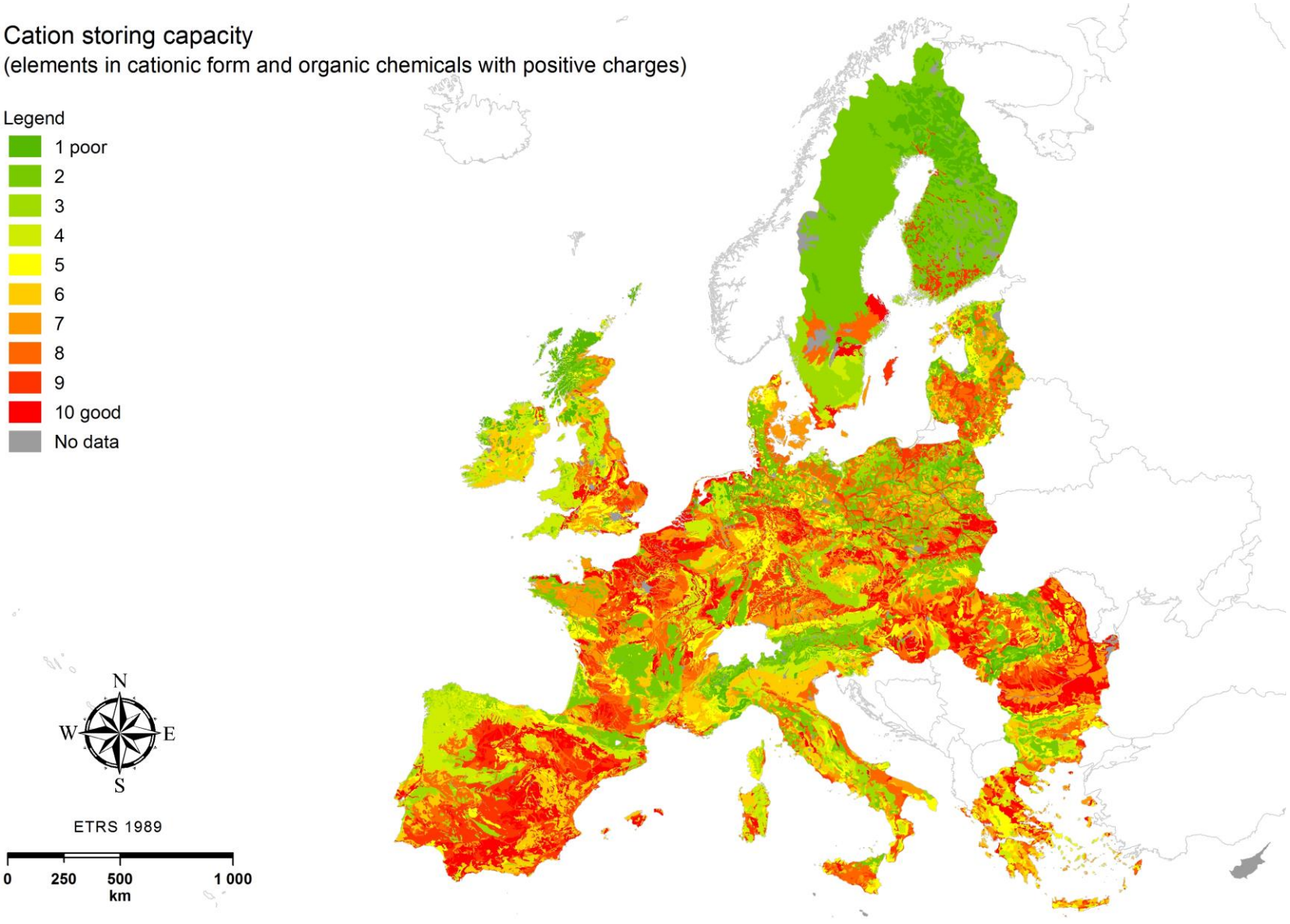

Figure 3. Map of cation storing capacity

16

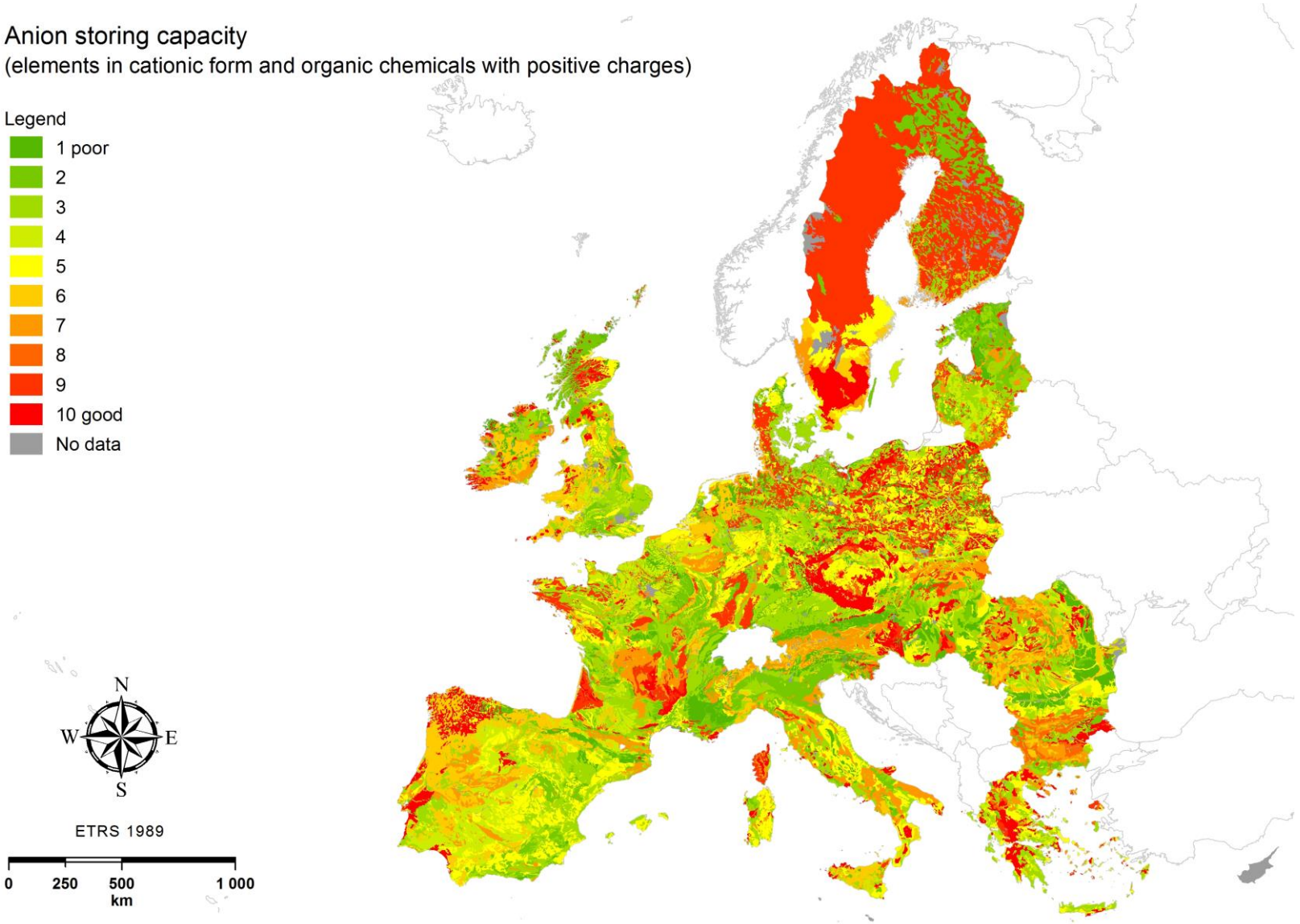

Figure 4. Map of anion storing capacity

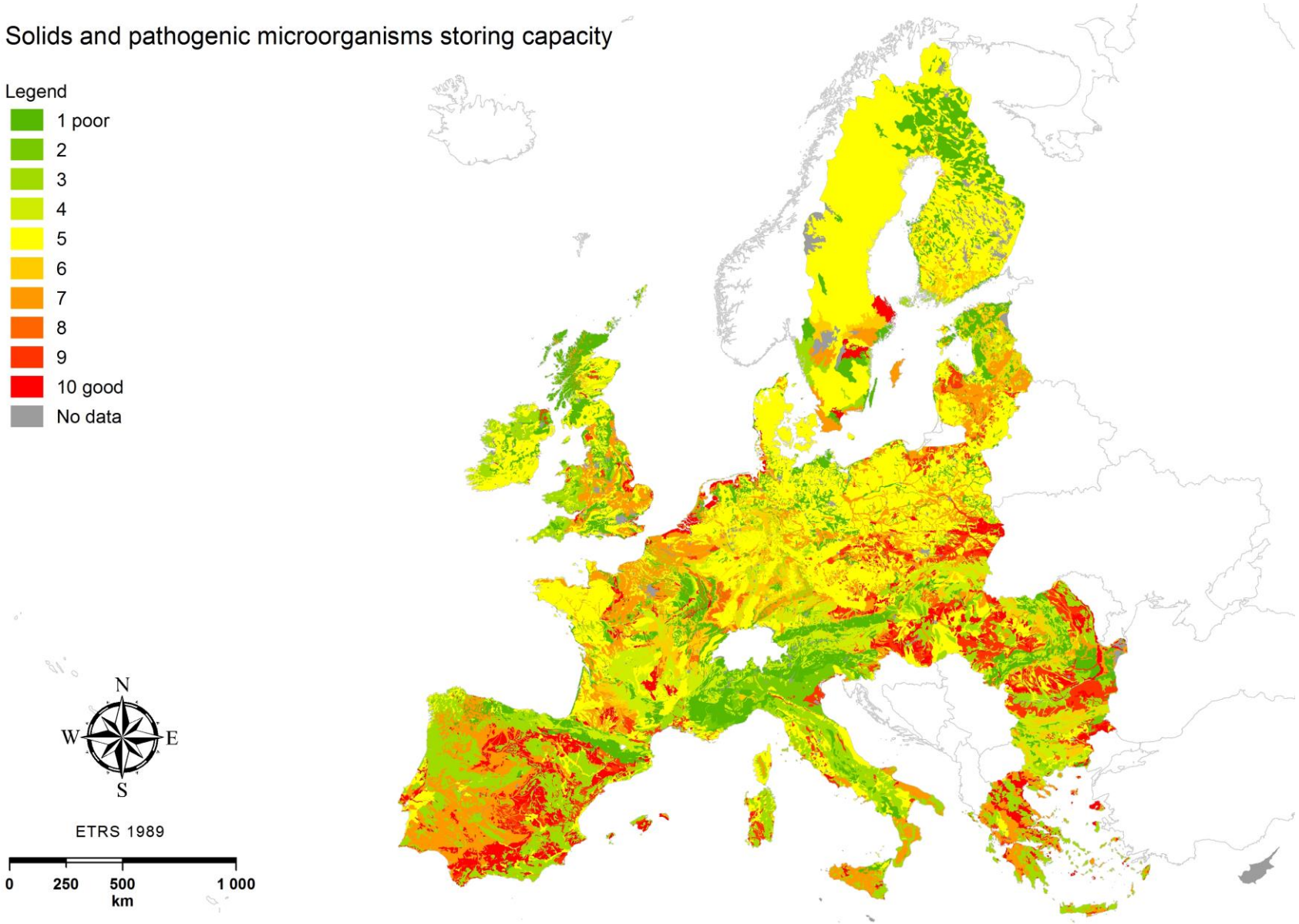

Figure 5. Map of solids and pathogenic microorganisms storing capacity

18

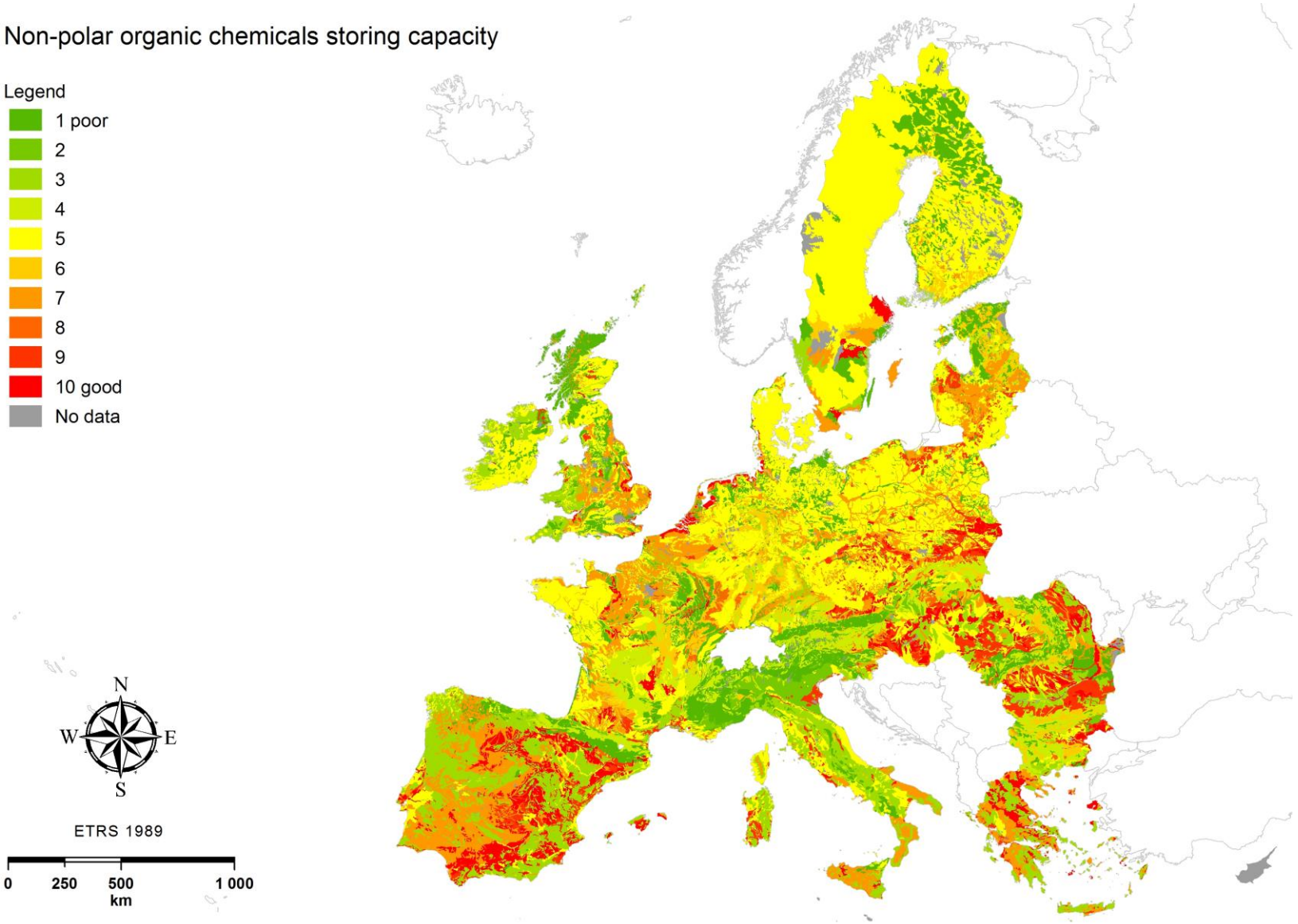

Figure 6. Map of non-polar organic chemicals storing capacity

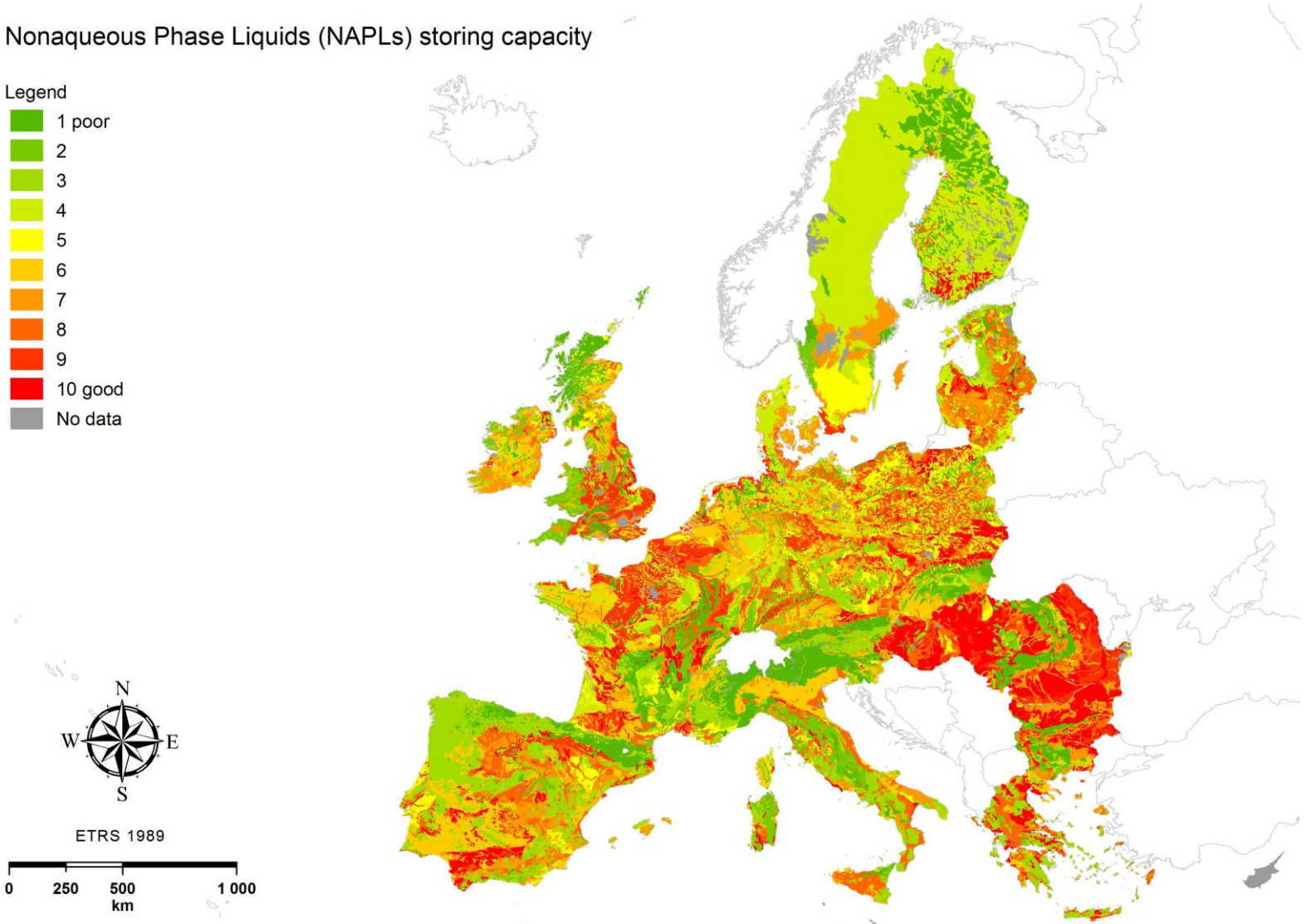

Figure 7. Map of nonaqueous phase liquid (NAPL) storing capacity

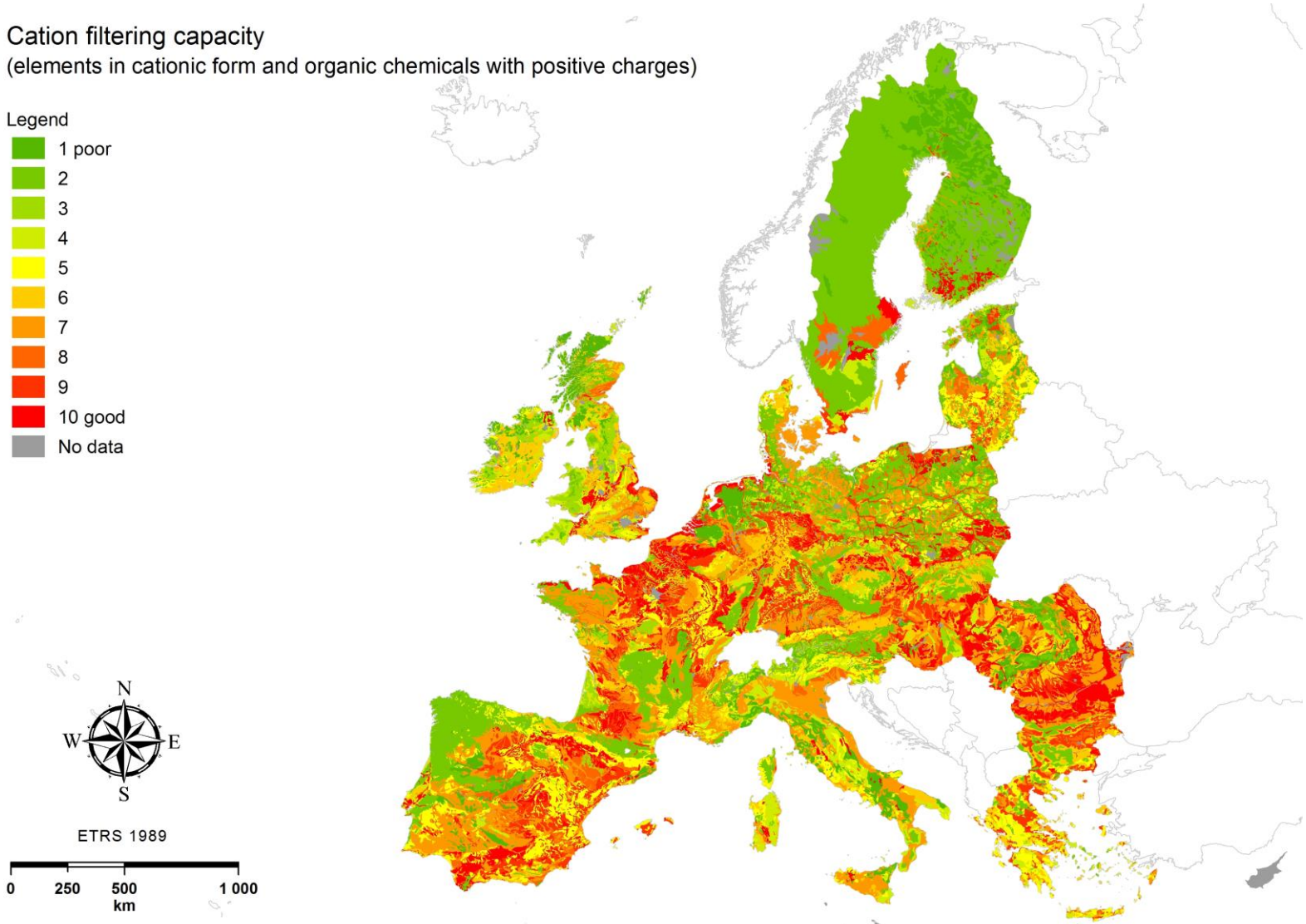

Figure 8. Map of cation filtering capacity

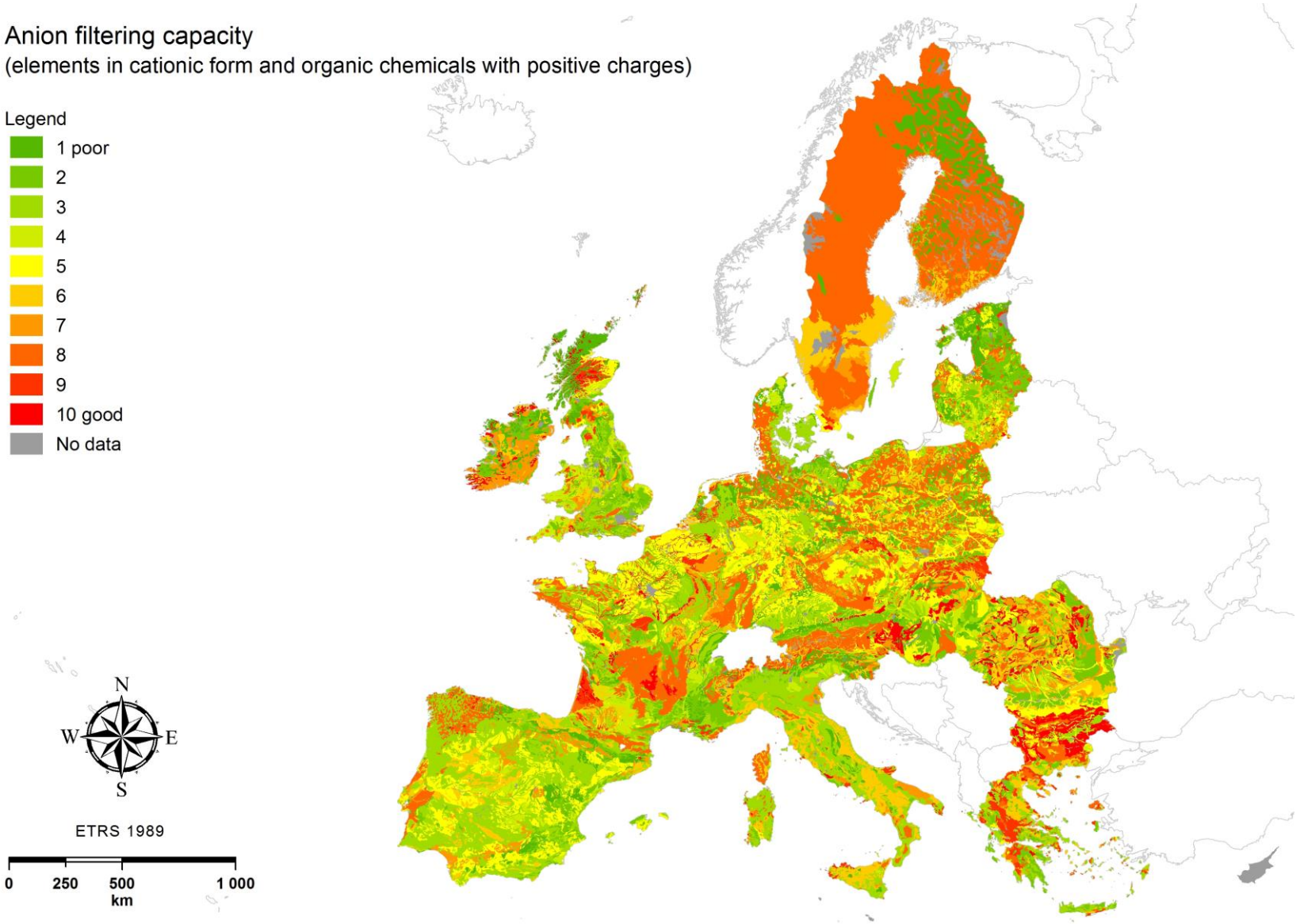

Figure 9. Map of anion filtering capacity

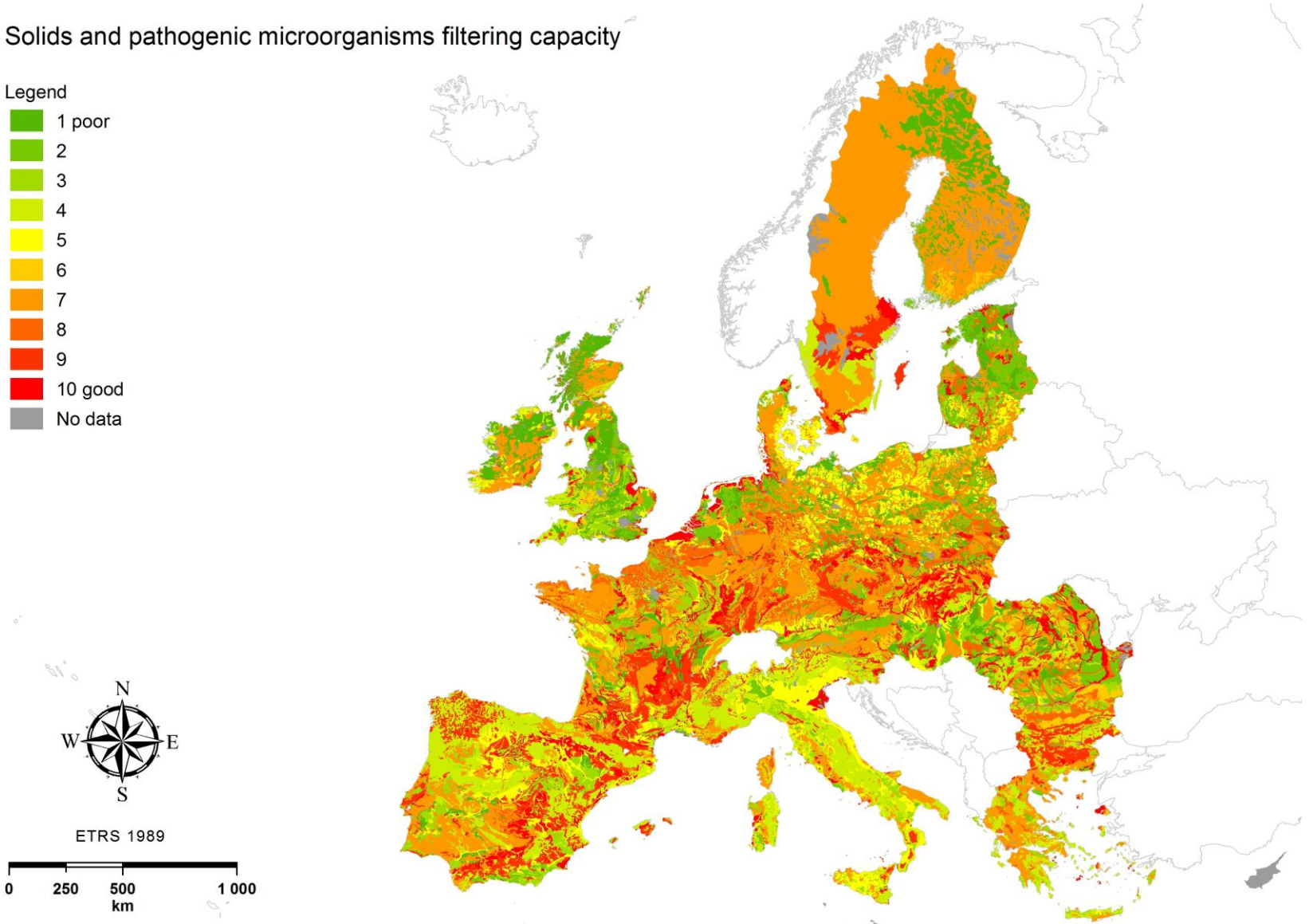

Figure 10. Map of solids and pathogenic microorganisms filtering capacity

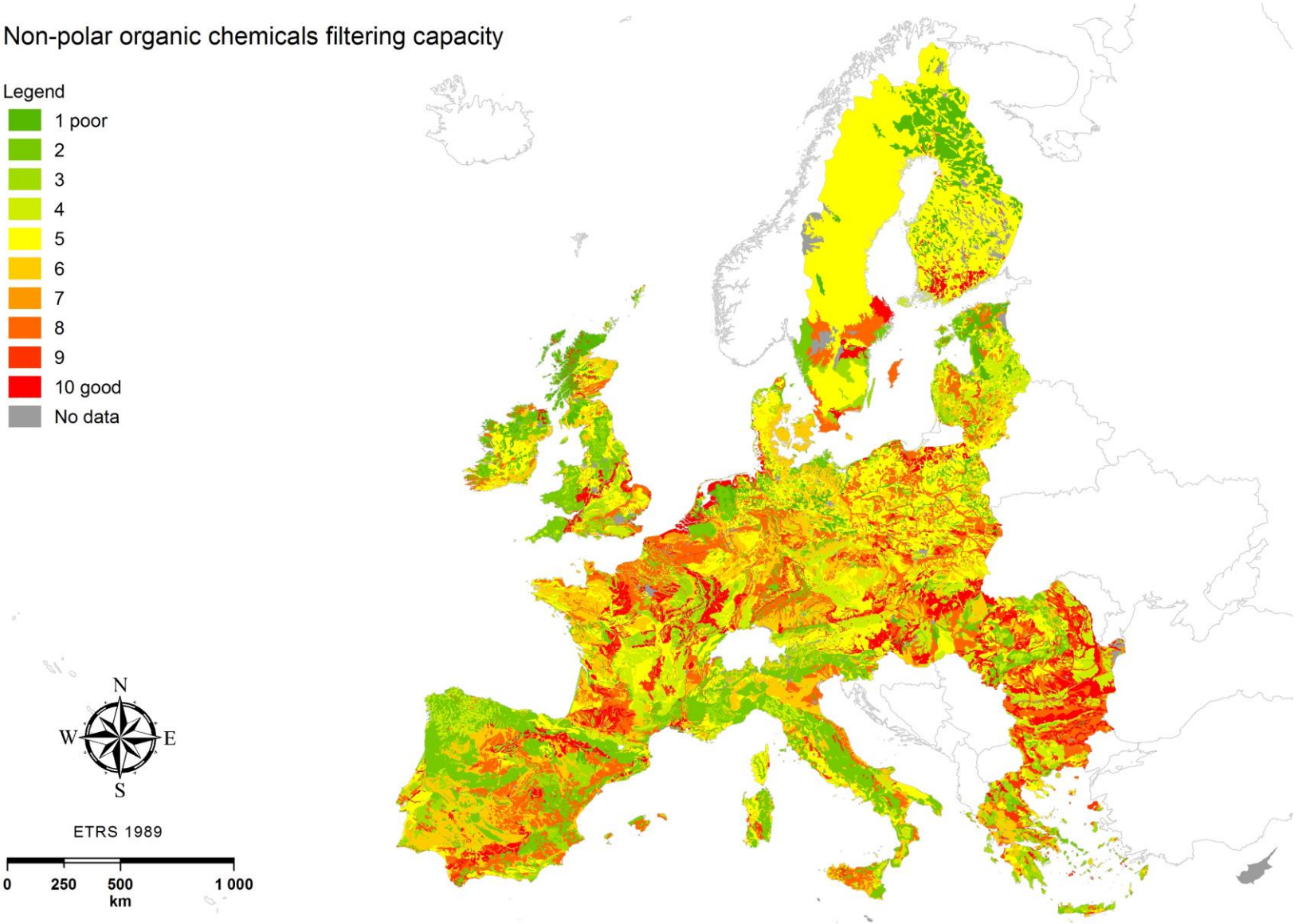

Figure 11. Map of non-polar organic chemicals filtering capacity

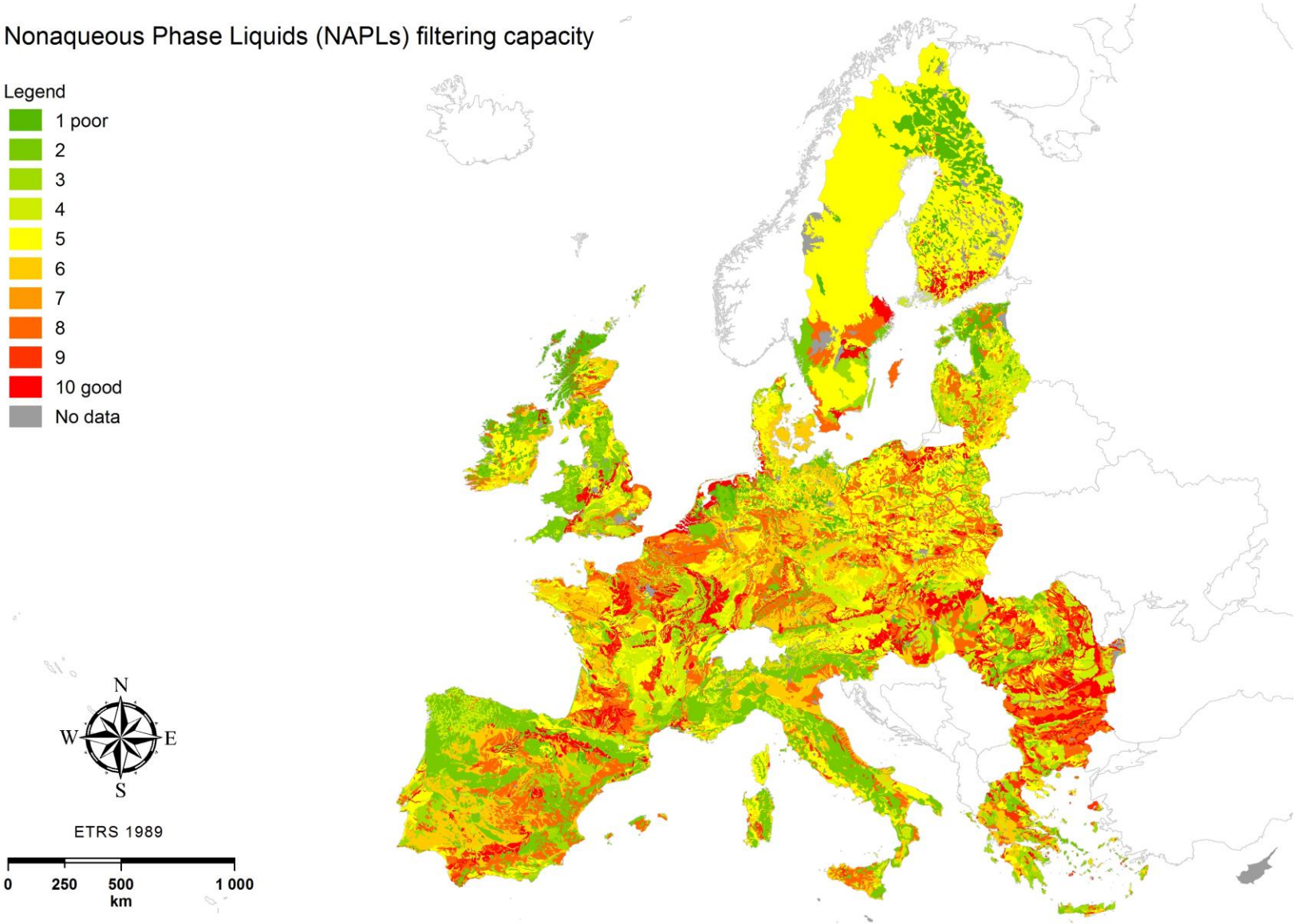

Figure 12. Map of nonaqueous phase liquid (NAPL) filtering capacity

As a next step we examined the distribution of storing and filtering properties of soils by European BGR (Fig. 13). Using the calculated normalized ten-stage capacity indices (WCI_{norm}) we characterized the storing and filtering ability of soils at a particular group of substances in a given region. Comparing the storing and filtering properties in Fig. 14 and 15 is visible that the Steppic, Pannonian and Black sea regions have the highest storing and filtering capacity in the case of substances in cationic forms and NAPLs, while the Boreal and Alpine regions can be characterized by the best ability to store and filter the anionic substances. The storing and filtering capability of regions are quite different in the case of non-polar organics, and similar differences were observed in the case of solids and pathogenic microorganisms.

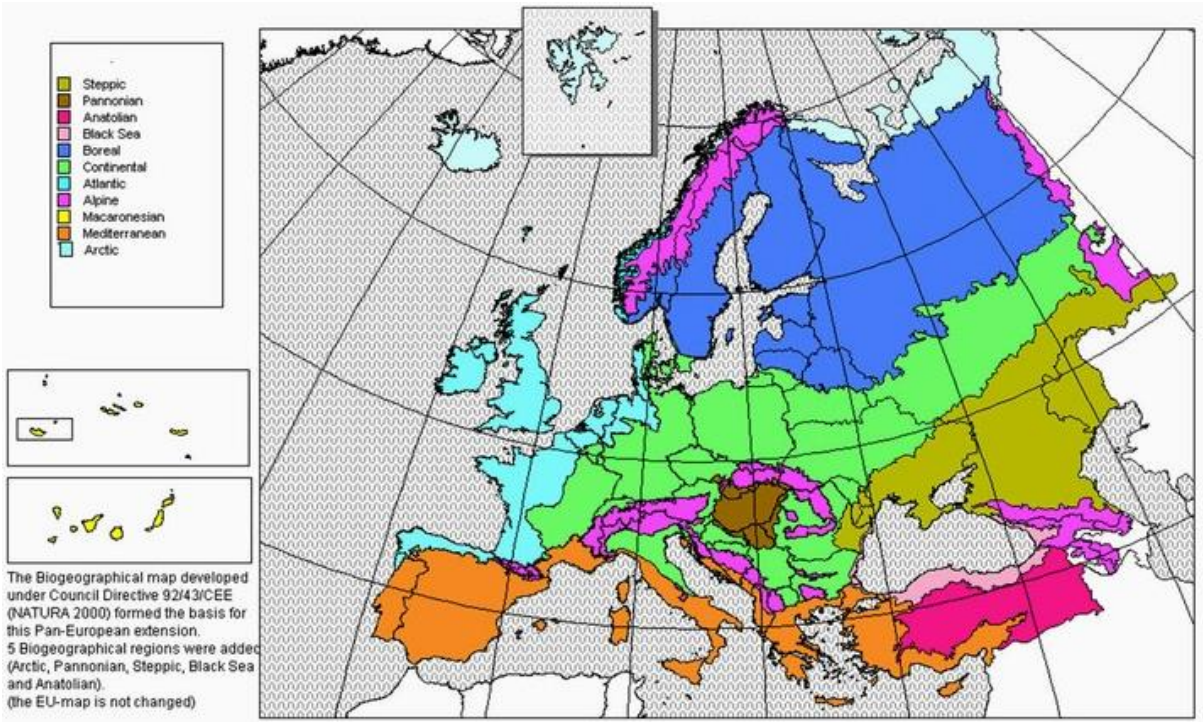

Figure 13. The Biogeographical Regions map of Europe [61]

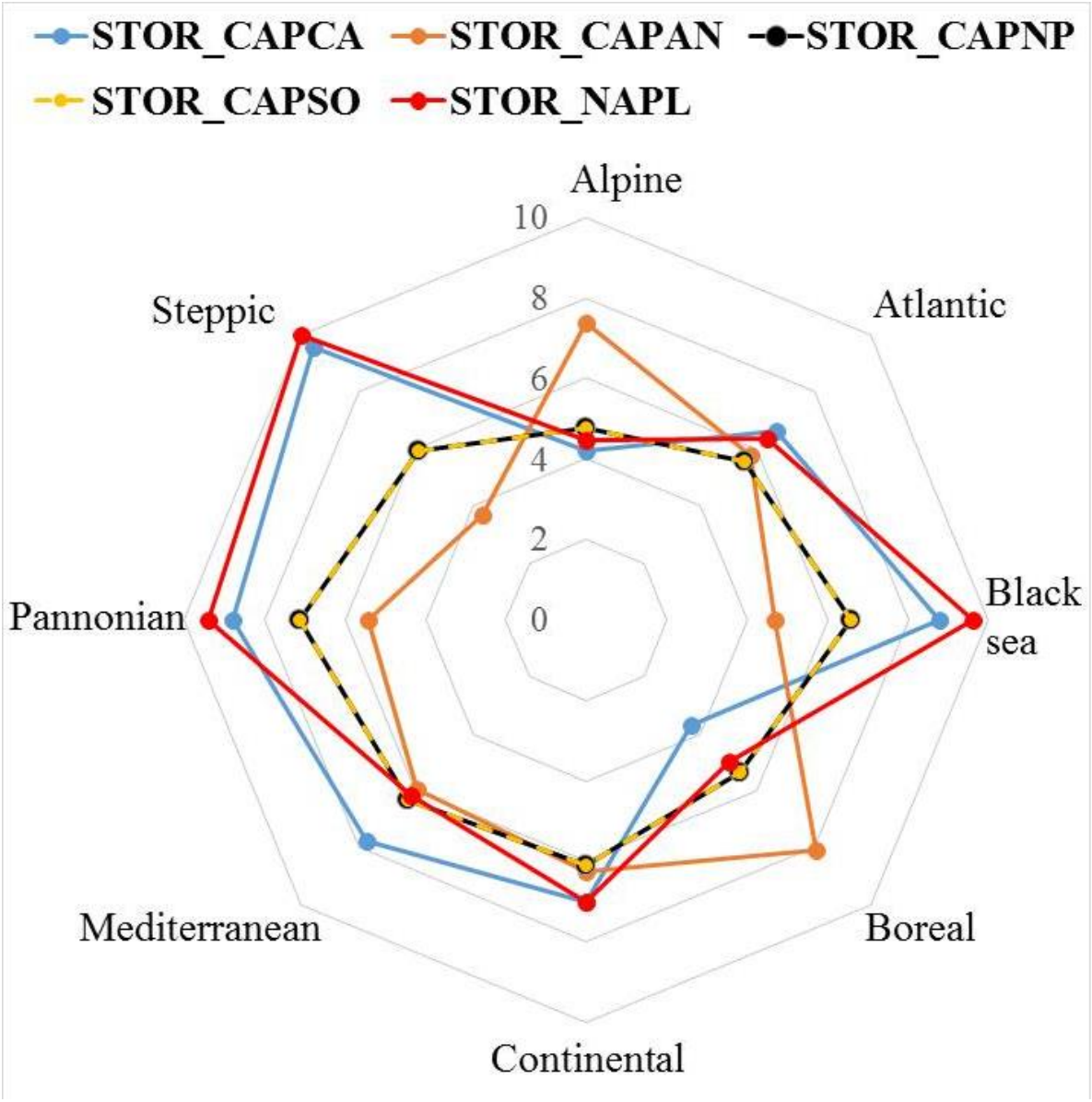

Figure 14. Comparison of WCI_{norm} values of European Biogeographical Regions to evaluate the spatial pattern of storing capacity of different substances (1: poor; 10: good)

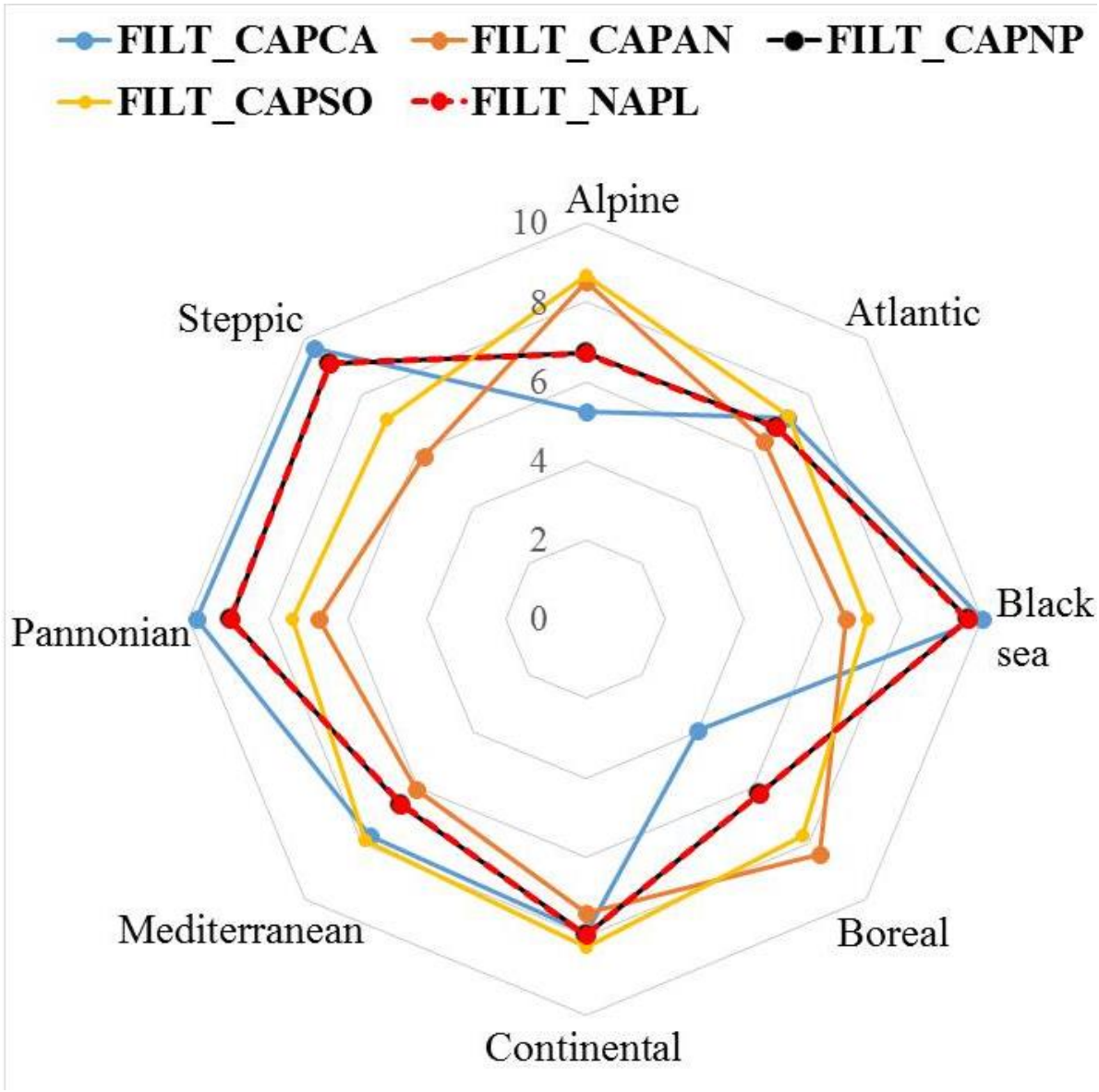

Figure 15 Comparison of WCI_{norm} values of European Biogeographical Regions to evaluate the spatial pattern of filtering capacity of different substances (1: poor; 10: good)

4. Conclusions

The presented algorithm to estimate the soil storing and filtering capacity based on large-scale soil map data is an important contribution to obtain basic Europe-wide environmental information. The knowledge of soil storing and filtering capacity for different substances is very useful during the environmental planning and modelling. These soil parameters (and the related sub-parameters) can usually not easily be determined or calculated by scientists without continent-wide extensive data access. With the publication of this study, the users will be able to download European datasets (storing and filtering capacity categories of soils in the case of different groups substances and furthermore the estimated CEC and SSA categories of soils at European scale) from the European Soil Data Centre.

The proposed algorithm provides a framework for the digital soil mapping of the soil storing and filtering functions at continental scale. The presented maps delineate areas where soil ability to store and filter a given type of substance is low and therefore the vulnerability of ecosystem in the case of soil pollution with this substance is high.

The study also suggests the possibility of improvement of the output datasets. As shown in the estimation algorithm above, a very complex estimation chain leads to the results, due to lack of basic spatial data needed. The development of European soil database, including the enlargement of soil monitoring systems will serve the growth of accuracy and reliability of soil function estimation methods.

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List of abbreviations and definitions

Abbreviations	Full name of parameters
BGR	Biogeographical region
ESDB	European soil database
NAPL	Nonaqueous phase liquid
PA	Percentage area
PTRDB	Pedotransfer Rules database
SMU	Soil mapping unit
STU	Soil taxonomy unit
WCI	Weightened capacity index
	Input parameters
BS_SUB	Base saturation of the subsoil
BS_TOP	Base saturation of the topsoil
CLIMANR	Code for the grouped climate categories
CORGRP_CAT	Code for the grouped CORINE 2006 categories
DR	Depth to rock
IL	Code for the presence of an impermeable layer within the soil profile of the STU
MIN_SUB	Subsoil mineralogy
MIN_TOP	Topsoil mineralogy
OC_TOP	Topsoil organic carbon content
PARMADO	Code for dominant parent material of the STU
PARMASE	Code for secondary parent material of the STU
PD_SUB	Subsoil packing density
PD_TOP	Topsoil packing density
PEAT	Peat
SLOPE-DOM	Dominant slope class of the STU
SLOPE-SEC	Secondary Slope class of the STU
TEXTDEPCHG	Depth class to a textural change of the dominant and/or secondary surface texture of the STU
TEXTSRFDOM	Dominant surface textural class of the STU
TEXTSRFSEC	Secondary surface textural class of the STU
TEXTSUBDOM	Dominant sub-surface textural class of the STU
TEXTSUBSEC	Secondary sub-surface textural class of the STU
VS	Volume of stones
WRB_ADJ	First soil adjective code of the STU from the World Reference Base (WRB) for Soil Resources
WRB_GRP	Soil reference group code of the STU from the World Reference Base (WRB) for Soil Resources
WRBFU	Full soil code of the STU from the World Reference Base (WRB) for Soil Resources
	Estimated parameters
AER	Aeration code
ANS_f	Anion sorption factor
BASE_SAT	Base saturation of the soil profile
CATS_f	Cation sorption factor
CEC_HUM	Cation exchange capacity related to humus content
CEC_MIN	Cation exchange capacity related to the soil minerals
CEC_SUM	Cation exchange capacity related to soil minerals and humus content
CPS	Clay percentage of the subsoil
CPT	Clay percentage of the topsoil
DG	Depth to the groundwater
DG_f	Groundwater depth factor

DISR	Depth to the impermeable rock
FILT_CAPAN	Anion filtering capacity (elements in anionic form and organic chemicals with negative charges)
FILT_CAPCA	Cation filtering capacity (elements in cationic form and organic chemicals with positive charges)
FILT_CAPNP	Non-polar organic chemicals filtering capacity
FILT_CAPSO	Solids and pathogenic microorganisms filtering capacity
FILT_NAPL	Nonaqueous Phase Liquids (NAPL) filtering capacity
HLT	Thickness of humus layer
HQ	Humus quality code
IL_f	Impermeable layer factor
IR	Infiltration rate
IR_f	Infiltration rate factor
LEACH_f	Leaching factor
MCPS	Modified clay percentage of the subsoil
MCPT	Modified clay percentage of the topsoil
MDSP	Maximum depth of soil profile with filter and storage properties
MIN_f	Mineral factor
MTDCH	Modified depth to a textural change code
SLOPEM	Modified slope category
SPCC	Clay content of the soil profile
SPD_f	Subsoil packing density factor
SPHC	Humus content of soil profile
SSA_HUM	Specific surface area related to humus content
SSA_MIN	Specific surface area related to soil minerals
SSA_SUM	Specific surface area related to soil minerals and humus content
STOR_CAPAN	Anion storing capacity (elements in anionic form and organic chemicals with negative charges)
STOR_CAPCA	Cation storing capacity (elements in cationic form and organic chemicals with positive charges)
STOR_CAPNP	Non-polar organic chemicals storing capacity
STOR_CAPSO	Solids and pathogenic microorganisms storing capacity
STOR_NAPL	Nonaqueous Phase Liquids (NAPL) storing capacity
TPD_f	Topsoil packing density factor
WB	Water balance code
WBM	Modified water balance

Input parameters used in the estimation procedures

TEXTDEPCHG: Depth class to a textural change of the dominant and/or secondary surface texture of the STU

---

0 No information
1 Textural change between 20 and 40 cm depth
2 Textural change between 40 and 60 cm depth
3 Textural change between 60 and 80 cm depth
4 Textural change between 80 and 120 cm depth
5 No textural change between 20 and 120 cm depth
6 Textural change between 20 and 60 cm depth
7 Textural change between 60 and 120 cm depth

TEXTSRFDOM: Dominant surface textural class of the STU

---

0 No information
9 No mineral texture (Peat soils)
1 Coarse (18% < clay and > 65% sand)
2 Medium (18% < clay < 35% and >= 15% sand, or 18% < clay and 15% < sand < 65%)
3 Medium fine (< 35% clay and < 15% sand)

4 Fine (35% < clay < 60%)
5 Very fine (clay > 60 %)

TEXTSRFSEC: Secondary surface textural class of the STU

---

0 No information
9 No mineral texture (Peat soils)
1 Coarse (18% < clay and > 65% sand)
2 Medium (18% < clay < 35% and >= 15% sand, or 18% < clay and 15% < sand < 65%)
3 Medium fine (< 35% clay and < 15% sand)
4 Fine (35% < clay < 60%)
5 Very fine (clay > 60 %)

TEXTSUBDOM: Dominant sub-surface textural class of the STU

---

0 No information
9 No mineral texture (Peat soils)
1 Coarse (18% < clay and > 65% sand)
2 Medium (18% < clay < 35% and >= 15% sand, or 18% < clay and 15% < sand < 65%)
3 Medium fine (< 35% clay and < 15% sand)
4 Fine (35% < clay < 60%)
5 Very fine (clay > 60 %)

TEXTSUBSEC :Secondary sub-surface textural class of the STU

---

0 No information
9 No mineral texture (Peat soils)
1 Coarse (18% < clay and > 65% sand)
2 Medium (18% < clay < 35% and >= 15% sand, or 18% < clay and 15% < sand < 65%)
3 Medium fine (< 35% clay and < 15% sand)
4 Fine (35% < clay < 60%)
5 Very fine (clay > 60 %)

PARMADO: Code for dominant parent material of the STU

---

0 No information
1000 consolidated-clastic-sedimentary rocks
1100 psephite or rudite
1110 conglomerate
1111 pudding stone
1120 breccia
1200 psammite or arenite
1210 sandstone
1211 calcareous sandstone
1212 ferruginous sandstone
1213 clayey sandstone
1214 quartzitiic sandstone/orthoquartzite
1215 micaceous sandstone
1220 arkose
1230 graywacke
1231 feldspathic graywacke
1300 pelite, lutite or argilite
1310 claystone/mudstone
1311 kaolinite
1312 bentonite
1320 siltstone
1400 facies bound rock
1410 flysch
1411 sandy flisch
1412 clayey and silty flysch
1413 conglomeratic flysch
1420 molasse
2000 sedimentary rocks (chemically precipitated, evaporated, or organogenic or biogenic in origin)
2100 calcareous rocks
2110 limestone
2111 hard limestone
2112 soft limestone
2113 marly limestone
2114 chalky limestone
2115 detrital limestone
2116 carbonaceous limestone
2117 lacustrine or freshwater limestone
2118 travertine/calcareous sinter
2119 cavernous limestone
2120 dolomite
2121 cavernous dolomite
2122 calcareous dolomite
2130 marlstone
2140 marl
2141 chalk marl
2142 gypsiferous marl
2150 chalk
2200 evaporites
2210 gypsum
2220 anhydrite
2230 halite
2300 siliceous rocks
2310 chert, hornstone, flint
2320 diatomite/radiolarite
3000 igneous rocks
3100 acid to intermediate plutonic rocks
3110 granite
3120 granodiorite

3130 diorite
3131 quartz diorite
3132 gabbro diorite
3140 syenite
3200 basic plutonic rocks
3210 gabbro
3300 ultrabasic plutonic rocks
3310 peridotite
3320 pyroxenite
3400 acid to intermediate volcanic rocks
3410 rhyolite
3411 obsidian
3412 quartz porphyrite
3420 dacite
3430 andesite
3431 porphyrite (interm,)
3440 phonolite
3441 tephritic phonolite
3450 trachyte
3500 basic to ultrabasic volcanic rocks
3510 basalt
3520 diabase
3530 pikrite
3600 dike rocks
3610 aplite
3620 pegmatite
3630 lamprophyre
3700 pyroclastic rocks (tephra)
3710 tuff/tuffstone
3711 agglomeratic tuff
3712 block tuff
3713 lapilli tuff
3720 tuffite
3721 sandy tuffite
3722 silty tuffite
3723 clayey tuffite
3730 volcanic scoria/volcanic breccia
3740 volcanic ash
3750 ignimbrite
3760 pumice
4000 metamorphic rocks
4100 weakly metamorphic rocks
4110 (meta-)shale/argilite
4120 slate
4121 graphitic slate
4200 acid regional metamorphic rocks
4210 (meta-)quartzite
4211 quartzite schist
4220 phyllite
4230 micaschist
4240 gneiss
4250 granulite (sensu stricto)
4260 migmatite
4300 basic regional metamorphic rocks
4310 greenschist
4311 prasinite
4312 chlorite
4313 talc schist
4320 amphibolite
4330 eclogite
4400 ultrabasic regional metamorphic rocks
4410 serpentinite
4411 greenstone
4500 calcareous regional metamorphic rocks
4510 marble
4520 calcschist, skam
4600 rocks formed by contact metamorphism
4610 contact slate
4611 nodular slate
4620 hornfels
4630 calsilicate rocks
4700 tectogenetic metamorphism rocks or cataclasmic metamorphism
4710 tectonic breccia
4720 cataclasite
4730 mylonite
5000 unconsolidated deposits (alluvium, weathering residuum and slope deposits)
5100 marine and estuarine sands
5110 pre-quaternary sand
5111 tertiary sand
5120 quaternary sand
5121 holocene coastal sand with shells
5122 delta sand
5200 marine and estuarine clays and silts
5210 pre-quaternary clay and silt
5211 tertiary clay
5212 tertiary silt
5220 quaternary clay and silt
5221 holocene clay
5222 holocene silt
5300 fluvial sands and gravels
5310 river terrace sand or gravel
5311 river terrace sand
5312 river terrace gravel
5320 floodplain sand or gravel
5321 floodplain sand
5322 floodplain gravel
5400 fluvial clays, silts and loams
5410 river clay and silt
5411 terrace clay and silt
5412 floodplain clay and silt
5420 river loam
5421 terrace loam
5430 overbank deposit
5431 floodplain clay and silt
5432 floodplain loam
5500 lake deposits
5510 lake sand and delta sand
5520 lake marl, bog lime

5530 lake silt
5600 residual and redeposited loams from silicate rocks
5610 residual loam
5611 stony loam
5612 clayey loam
5620 redeposited loam
5621 running-ground
5700 residual and redeposited clays from calcareous rocks
5710 residual clay
5711 clay with flints
5712 ferruginous residual clay
5713 calcareous clay
5714 non-calcareous clay
5715 marly clay
5720 redeposited clay
5721 stony clay
5800 slope deposits
5810 slope-wash alluvium
5820 colluvial deposit
5830 talus scree
5831 stratified slope deposits
6000 unconsolidated glacial deposits/glacial drift
6100 morainic deposits
6110 glacial till
6111 boulder clay
6120 glacial debris
6200 glaciofluvial deposits
6210 outwash sand, glacial sand
6220 outwash gravels glacial gravels
6300 glaciolacustrine deposits
6310 varves
7000 eolian deposits
7100 loess
7110 loamy loess
7120 sandy loess
7200 eolian sands
7210 dune sand
7220 cover sand
8000 organic materials
8100 peat (mires)
8110 rainwater fed moor peat (raised bog)
8111 folic peat
8112 fibric peat
8113 terric peat
8120 groundwater fed bog peat
8200 slime and ooze deposits
8210 gyttja, sapropel
8300 carbonaceaous rocks (caustobiolite)
8310 lignite (brown coal)
8320 hard coal
8330 anthracite
9000 anthropogenic deposits
9100 redeposited natural materials
9110 sand and gravel fill
9120 loamy fill
9200 dump deposits
9210 rubble/rubbish
9220 industrial ashes and slag
9230 industrial sludge
9240 industrial waste
9300 anthropogenic organic materials

PARMASE: Code for secondary parent material of the STU

---

0 No information
1000 consolidated-clastic-sedimentary rocks
1100 psephite or rudite
1110 conglomerate
1111 pudding stone
1120 breccia
1200 psammite or arenite
1210 sandstone
1211 calcareous sandstone
1212 ferruginous sandstone
1213 clayey sandstone
1214 quartzitiic sandstone/orthoquartzite
1215 micaceous sandstone
1220 arkose
1230 graywacke
1231 feldspathic graywacke
1300 pelite, lutite or argilite
1310 claystone/mudstone
1311 kaolinite
1312 bentonite
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1400 facies bound rock
1410 flysch
1411 sandy flisch
1412 clayey and silty flysch
1413 conglomeratic flysch
1420 molasse
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2112 soft limestone
2113 marly limestone
2114 chalky limestone
2115 detrital limestone
2116 carbonaceous limestone
2117 lacustrine or freshwater limestone
2118 travertine/calcareous sinter
2119 cavernous limestone

2120 dolomite
2121 cavernous dolomite
2122 calcareous dolomite
2130 marlstone
2140 marl
2141 chalk marl
2142 gypsiferous marl
2150 chalk
2200 evaporites
2210 gypsum
2220 anhydrite
2230 halite
2300 siliceous rocks
2310 chert, hornstone, flint
2320 diatomite/radiolarite
3000 igneous rocks
3100 acid to intermediate plutonic rocks
3110 granite
3120 granodiorite
3130 diorite
3131 quartz diorite
3132 gabbro diorite
3140 syenite
3200 basic plutonic rocks
3210 gabbro
3300 ultrabasic plutonic rocks
3310 peridotite
3320 pyroxenite
3400 acid to intermediate volcanic rocks
3410 rhyolite
3411 obsidian
3412 quartz porphyrite
3420 dacite
3430 andesite
3431 porphyrite (interm,)
3440 phonolite
3441 tephritic phonolite
3450 trachyte
3500 basic to ultrabasic volcanic rocks
3510 basalt
3520 diabase
3530 pikrite
3600 dike rocks
3610 aplite
3620 pegmatite
3630 lamprophyre
3700 pyroclastic rocks (tephra)
3710 tuff/tuffstone
3711 agglomeratic tuff
3712 block tuff
3713 lapilli tuff
3720 tuffite
3721 sandy tuffite
3722 silty tuffite
3723 clayey tuffite
3730 volcanic scoria/volcanic breccia
3740 volcanic ash
3750 ignimbrite
3760 pumice
4000 metamorphic rocks
4100 weakly metamorphic rocks
4110 (meta-)shale/argilite
4120 slate
4121 graphitic slate
4200 acid regional metamorphic rocks
4210 (meta-)quartzite
4211 quartzite schist
4220 phyllite
4230 micaschist
4240 gneiss
4250 granulite (sensu stricto)
4260 migmatite
4300 basic regional metamorphic rocks
4310 greenschist
4311 prasinite
4312 chlorite
4313 talc schist
4320 amphibolite
4330 eclogite
4400 ultrabasic regional metamorphic rocks
4410 serpentinite
4411 greenstone
4500 calcareous regional metamorphic rocks
4510 marble
4520 calcschist, skam
4600 rocks formed by contact metamorphism
4610 contact slate
4611 nodular slate
4620 hornfels
4630 calsilicate rocks
4700 tectogenetic metamorphism rocks or cataclasmic metamorphism
4710 tectonic breccia
4720 cataclasite
4730 mylonite
5000 unconsolidated deposits (alluvium, weathering residuum and slope deposits)
5100 marine and estuarine sands
5110 pre-quaternary sand
5111 tertiary sand
5120 quaternary sand
5121 holocene coastal sand with shells
5122 delta sand
5200 marine and estuarine clays and silts
5210 pre-quaternary clay and silt
5211 tertiary clay
5212 tertiary silt
5220 quaternary clay and silt
5221 holocene clay

5222 holocene silt
5300 fluvial sands and gravels
5310 river terrace sand or gravel
5311 river terrace sand
5312 river terrace gravel 5320 floodplain sand or gravel
5321 floodplain sand
5322 floodplain gravel
5400 fluvial clays, silts and loams
5410 river clay and silt
5411 terrace clay and silt
5412 floodplain clay and silt
5420 river loam
5421 terrace loam
5430 overbank deposit
5431 floodplain clay and silt
5432 floodplain loam
5500 lake deposits
5510 lake sand and delta sand
5520 lake marl, bog lime
5530 lake silt
5600 residual and redeposited loams from silicate rocks
5610 residual loam
5611 stony loam
5612 clayey loam
5620 redeposited loam
5621 running-ground
5700 residual and redeposited clays from calcareous rocks
5710 residual clay
5711 clay with flints
5712 ferruginous residual clay
5713 calcareous clay
5714 non-calcareous clay
5715 marly clay
5720 redeposited clay
5721 stony clay
5800 slope deposits
5810 slope-wash alluvium
5820 colluvial deposit
5830 talus scree
5831 stratified slope deposits
6000 unconsolidated glacial deposits/glacial drift
6100 morainic deposits
6110 glacial till
6111 boulder clay
6120 glacial debris
6200 glaciofluvial deposits
6210 outwash sand, glacial sand
6220 outwash gravels glacial gravels
6300 glaciolacustrine deposits
6310 varves
7000 eolian deposits
7100 loess
7110 loamy loess
7120 sandy loess
7200 eolian sands
7210 dune sand
7220 cover sand
8000 organic materials
8100 peat (mires)
8110 rainwater fed moor peat (raised bog)
8111 folic peat
8112 fibric peat
8113 terric peat
8120 groundwater fed bog peat
8200 slime and ooze deposits
8210 gyttja, sapropel
8300 carbonaceaous rocks (caustobiolite)
8310 lignite (brown coal)
8320 hard coal 8330 anthracite
9000 anthropogenic deposits
9100 redeposited natural materials
9110 sand and gravel fill
9120 loamy fill
9200 dump deposits
9210 rubble/rubbish
9220 industrial ashes and slag
9230 industrial sludge
9240 industrial waste
9300 anthropogenic organic materials

WRB_GRP: Soil reference group code of the STU from the World Reference Base (WRB) for Soil Resources

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AB Albeluvisol
AC Acrisol
AL Alisol
AN Andosol
AR Arenosol
AT Anthrosol
CH Chernozem
CL Calcisol
CM Cambisol
CR Cryosol
DU Durisol
FL Fluvisol
FR Ferralsol
GL Gleysol
GY Gypsisol
HS Histosol
KS Kastanozem
LP Leptosol
LV Luvisol
LX Lixisol
NT Nitisol
PH Phaeozem
PL Planosol

PT Plinthosol
PZ Podzol
RG Regosol
SC Solonchak
SN Solonetz
UM Umbrisol
VR Vertisol
1 Town
2 Soil disturbed by man
3 Water body
4 Marsh
5 Glacier
6 Rock outcrops

WRB_ADJ: First soil adjective code of the STU from the World Reference Base (WRB) for Soil Resources
---
II Lamellic
Iv Luvic
Ix Lixic
ab Albic
ac Acric
ad Aridic
ae Aceric
ah Anthropic
ai Aric
al Alic
am Anthric
an Andic
ao Acroxic
ap Abruptic
aq Anthraquic
ar Arenic
au Alumic
ax Alcalic
az Arzic
ca Calcaric
cb Carbic
cc Calcic
ch Chernic
cl Chloridic
cn Carbonatic
cr Chromic
ct Cutanic
cy Cryic
dn Densic
du Duric
dy Dystric
es Eutrisilic
et Entic
eu Eutric
fg Fragic
fi Fibric
fl Ferralic
fo Folic
fr Ferric
fu Fulvic
fv Fluvic
ga Garbic
gc Glacic
ge Gelic
gi Gibbsic
gl Gleyic
gm Grumic
gp Gypsiric
gr Geric
gs Glossic
gt Gelistagnic
gy Gypsic
gz Greyic
ha Haplic
hg Hydragric
hi Histic
hk Hyperskeletic
ht Hortic
hu Humic
hy Hydric
ir Irragric
le Leptic
li Lithic
me Melanic
mg Magnesic
mo Mollic
ms Mesotrophic
mz Mazic
na Natric
ni Nitic
oa Oxyaquic
oh Ochric
om Ombric
or Orthic
pa Plaggic
pc Petroccic
pd Petroduric
pe Pellic
pf Profondic
pg Petrogypsic
ph Pachic
pi Placic
pl Plinthic
pn Planic
po Posic
pp Petroplinthic
pr Protic
ps Petrosalic
pt Petric
rd Reductic
rg Regic
rh Rheic
ro Rhodic
rp Ruptic
rs Rustic

ru Rubic
rz Rendzic
sa Sapric
sd Spodic
si Silic
sk Skeletic
sl Siltic
so Sodic
sp Spolic
st Stagnic
su Sulphatic
sz Salic
tf Tephric
ti Thionic
tr Terric
tu Turbic
tx Toxic
ty Takyric
ub Urbic
um Umbric
vi Vitric
vm Vermic
vr Vertic
vt Vetic
xa Xanthic
ye Yermic
1 Town
2 Soil disturbed by man
3 Water body
4 Marsh
5 Glacier
6 Rock outcrops

WRBFU: Full soil code of the STU from the World Reference Base (WRB) for Soil Resources

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AB Albeluvisol
ABal Alic Albeluvisol
ABap Abruptic Albeluvisol
ABar Arenic Albeluvisol
ABau Alumic Albeluvisol
ABeun Endoeutric Albeluvisol
ABfg Fragic Albeluvisol
ABfr Ferric Albeluvisol
ABge Gelic Albeluvisol
ABgl Gleyic Albeluvisol
ABha Haplic Albeluvisol
ABhi Histic Albeluvisol
ABsl Siltic Albeluvisol
ABst Stagnic Albeluvisol
ABum Umbric Albeluvisol
AC Acrisol
ACab Albic Acrisol
ACan Andic Acrisol
ACap Abruptic Acrisol
ACar Arenic Acrisol
ACau Alumic Acrisol
ACcr Chromic Acrisol
ACdyh Hyperdystric Acrisol
ACfr Ferric Acrisol
ACgl Gleyic Acrisol
ACgr Geric Acrisol
ACha Haplic Acrisol
AChu Humic Acrisol
ACle Leptic Acrisol
ACll Lamellic Acrisol
ACohh Hyperochric Acrisol
ACpf Profondic Acrisol
ACpl Plinthic Acrisol
ACro Rhodic Acrisol
ACsk Skeletic Acrisol
ACst Stagnic Acrisol
ACum Umbric Acrisol
ACvi Vitric Acrisol
ACvt Vetic Acrisol
AL Alisol
ALab Albic Alisol
ALan Andic Alisol
ALap Abruptic Alisol
ALar Arenic Alisol
ALcr Chromic Alisol
ALdyh Hyperdystric Alisol
ALfr Ferric Alisol
ALgl Gleyic Alisol
ALha Haplic Alisol
ALhu Humic Alisol
ALll Lamellic Alisol
ALni Nitic Alisol
ALpf Profondic Alisol
ALpl Plinthic Alisol
ALro Rhodic Alisol
ALsk Skeletic Alisol
ALst Stagnic Alisol
ALum Umbric Alisol
ALvr Vertic Alisol
AN Andosol
ANao Acroxic Andosol
ANar Arenic Andosol
ANca Calcaric Andosol
ANdu Duric Andosol
ANdy Dystric Andosol
ANes Eutrisilic Andosol
ANeu Eutric Andosol
ANfu Fulvic Andosol
ANgl Gleyic Andosol
ANha Haplic Andosol
ANhi Histic Andosol
ANhy Hydric Andosol
ANle Leptic Andosol
ANlv Luvic Andosol
ANme Melanic Andosol
ANmo Mollic Andosol

ANph Pachic Andosol
ANpi Placic Andosol
ANsi Silic Andosol
ANsk Skeletic Andosol
ANso Sodic Andosol
ANth Thaptic Andosol
ANum Umbric Andosol
ANvi Vitric Andosol
ANvt Vetic Andosol
AR Arenosol
ARab Albic Arenosol
ARad Aridic Arenosol
ARca Calcaric Arenosol
ARduw Hypoduric Arenosol
ARdy Dystric Arenosol
AReu Eutric Arenosol
ARfg Fragic Arenosol
ARfl Ferralic Arenosol
ARge Gelic Arenosol
ARgl Gleyic Arenosol
ARgp Gypsiric Arenosol
ARha Haplic Arenosol
ARll Lamellic Arenosol
ARlvw Hypoluvic Arenosol
ARpl Plinthic Arenosol
ARpr Protic Arenosol
ARru Rubic Arenosol
ARszw Hyposalic Arenosol
ARtf Tephric Arenosol
ARye Yermic Arenosol
AT Anthrosol
ATar Arenic Anthrosol
ATfl Ferralic Anthrosol
ATgl Gleyic Anthrosol
AThg Hydragric Anthrosol
ATht Hortic Anthrosol
ATir Irragric Anthrosol
ATlv Luvic Anthrosol
ATpa Plaggic Anthrosol
ATrg Regic Anthrosol
ATsd Spodic Anthrosol
ATst Stagnic Anthrosol
ATtr Terric Anthrosol
CH Chernozem
CHcc Calcic Chernozem
CHch Chernic Chernozem
CHgl Gleyic Chernozem
CHgs Glossic Chernozem
CHha Haplic Chernozem
CHlv Luvic Chernozem
CHsl Siltic Chernozem
CHvm Vermic Chernozem
CHvr Vertic Chernozem
CL Calcisol
CLad Aridic Calcisol
CLcch Hypercalcic Calcisol
CLccw Hypocalcic Calcisol
CLgl Gleyic Calcisol
CLha Haplic Calcisol
CLle Leptic Calcisol
CLlv Luvic Calcisol
CLohh Hyperochric Calcisol
CLpt Petric Calcisol
CLsk Skeletic Calcisol
CLso Sodic Calcisol
CLszn Endosalic Calcisol
CLty Takyric Calcisol
CLvr Vertic Calcisol
CLye Yermic Calcisol
CM Cambisol
CMad Aridic Cambisol
CMan Andic Cambisol
CMca Calcaric Cambisol
CMcr Chromic Cambisol
CMdy Dystric Cambisol
CMeu Eutric Cambisol
CMfl Ferralic Cambisol
CMfv Fluvic Cambisol
CMge Gelic Cambisol
CMgl Gleyic Cambisol
CMgp Gypsiric Cambisol
CMgt Gelistagnic Cambisol
CMha Haplic Cambisol
CMle Leptic Cambisol
CMmo Mollic Cambisol
CMohh Hyperochric Cambisol
CMpl Plinthic Cambisol
CMro Rhodic Cambisol
CMsk Skeletic Cambisol
CMso Sodic Cambisol
CMst Stagnic Cambisol
CMszn Endosalic Cambisol
CMty Takyric Cambisol
CMvi Vitric Cambisol
CMvr Vertic Cambisol
CMye Yermic Cambisol
CR Cryosol
CRad Aridic Cryosol
CRan Andic Cryosol
CRcc Calcic Cryosol
CRgc Glacic Cryosol
CRgl Gleyic Cryosol
CRgy Gypsic Cryosol
CRha Haplic Cryosol
CRhi Histic Cryosol
CRle Leptic Cryosol
CRli Lithic Cryosol
CRmo Mollic Cryosol
CRna Natric Cryosol
CRoa Oxyaquic Cryosol
CRst Stagnic Cryosol
CRsz Salic Cryosol
CRti Thionic Cryosol
CRtu Turbic Cryosol

CRum Umbric Cryosol
CRye Yermic Cryosol
DU Durisol
DUad Aridic Durisol
DUar Arenic Durisol
DUcc Calcic Durisol
DUcr Chromic Durisol
DUgy Gypsic Durisol
DUha Haplic Durisol
DUle Leptic Durisol
DUlv Luvic Durisol
DUohh Hyperochric Durisol
DUpt Petric Durisol
DUty Takyric Durisol
DUvr Vertic Durisol
DUye Yermic Durisol
FL Fluvisol
FLad Aridic Fluvisol
FLar Arenic Fluvisol
FLca Calcaric Fluvisol
FLdy Dystric Fluvisol
FLeu Eutric Fluvisol
FLge Gelic Fluvisol
FLgl Gleyic Fluvisol
FLgp Gypsiric Fluvisol
FLha Haplic Fluvisol
FLhi Histic Fluvisol
FLhu Humic Fluvisol
FLmo Mollic Fluvisol
FLsk Skeletic Fluvisol
FLso Sodic Fluvisol
FLst Stagnic Fluvisol
FLsz Salic Fluvisol
FLtf Tephric Fluvisol
FLti Thionic Fluvisol
FLty Takyric Fluvisol
FLum Umbric Fluvisol
FLye Yermic Fluvisol
FR Ferralsol
FRac Acric Ferralsol
FRan Andic Ferralsol
FRar Arenic Ferralsol
FRau Alumic Ferralsol
FRdyh Hyperdystric Ferralsol
FReuh Hypereutric Ferralsol
FRfr Ferric Ferralsol
FRgi Gibbsic Ferralsol
FRgl Gleyic Ferralsol
FRgr Geric Ferralsol
FRha Haplic Ferralsol
FRhi Histic Ferralsol
FRhu Humic Ferralsol
FRlx Lixic Ferralsol
FRmo Mollic Ferralsol
FRpl Plinthic Ferralsol
FRpo Posic Ferralsol
FRro Rhodic Ferralsol
FRstn Endostagnic Ferralsol
FRum Umbric Ferralsol
FRvt Vetic Ferralsol
FRxa Xanthic Ferralsol
GL Gleysol
GLan Andic Gleysol
GLap Abruptic Gleysol
GLaq Anthraquic Gleysol
GLar Arenic Gleysol
GLau Alumic Gleysol
GLax Alcalic Gleysol
GLca Calcaric Gleysol
GLcc Calcic Gleysol
GLdy Dystric Gleysol
GLeu Eutric Gleysol
GLge Gelic Gleysol
GLgy Gypsic Gleysol
GLha Haplic Gleysol
GLhi Histic Gleysol
GLhu Humic Gleysol
GLmo Mollic Gleysol
GLpl Plinthic Gleysol
GLso Sodic Gleysol
GLszn Endosalic Gleysol
GLtf Tephric Gleysol
GLti Thionic Gleysol
GLtx Toxic Gleysol
GLty Takyric Gleysol
GLum Umbric Gleysol
GLvi Vitric Gleysol
GY Gypsisol
GYad Aridic Gypsisol
GYaz Arzic Gypsisol
GYcc Calcic Gypsisol
GYdu Duric Gypsisol
GYgyh Hypergypsic Gypsisol
GYgyw Hypogypsic Gypsisol
GYha Haplic Gypsisol
GYle Leptic Gypsisol
GYlv Luvic Gypsisol
GYohh Hyperochric Gypsisol
GYpt Petric Gypsisol
GYsk Skeletic Gypsisol
GYso Sodic Gypsisol
GYszn Endosalic Gypsisol
GYty Takyric Gypsisol
GYvr Vertic Gypsisol
GYye Yermic Gypsisol
HS Histosol
HSax Alcalic Histosol
HScy Cryic Histosol
HSdy Dystric Histosol
HSeu Eutric Histosol
HSfi Fibric Histosol
HSfo Folic Histosol
HSgc Glacic Histosol
HSge Gelic Histosol

HSom Ombric Histosol
HSrh Rheic Histosol
HSsa Sapric Histosol
HSsz Salic Histosol
HSti Thionic Histosol
HStx Toxic Histosol
KS Kastanozem
KSam Anthric Kastanozem
KScc Calcic Kastanozem
KScr Chromic Kastanozem
KSgy Gypsic Kastanozem
KSha Haplic Kastanozem
KSlv Luvic Kastanozem
KSsl Siltic Kastanozem
KSsow Hyposodic Kastanozem
KSvr Vertic Kastanozem
LP Leptosol
LPad Aridic Leptosol
LPca Calcaric Leptosol
LPdy Dystric Leptosol
LPeu Eutric Leptosol
LPge Gelic Leptosol
LPgl Gleyic Leptosol
LPgp Gypsiric Leptosol
LPha Haplic Leptosol
LPhk Hyperskeletic Leptosol
LPhu Humic Leptosol
LPli Lithic Leptosol
LPmo Mollic Leptosol
LPrz Rendzic Leptosol
LPum Umbric Leptosol
LPvr Vertic Leptosol
LPye Yermic Leptosol
LV Luvisol
LVab Albic Luvisol
LVan Andic Luvisol
LVar Arenic Luvisol
LVcc Calcic Luvisol
LVcr Chromic Luvisol
LVct Cutanic Luvisol
LVdy Dystric Luvisol
LVfr Ferric Luvisol
LVgl Gleyic Luvisol
LVha Haplic Luvisol
LVle Leptic Luvisol
LVll Lamellic Luvisol
LVohh Hyperochric Luvisol
LVpf Profondic Luvisol
LVro Rhodic Luvisol
LVsow Hyposodic Luvisol
LVst Stagnic Luvisol
LVvi Vitric Luvisol
LVvr Vertic Luvisol
LX Lixisol
LXab Albic Lixisol
LXan Andic Lixisol
LXap Abruptic Lixisol
LXar Arenic Lixisol
LXcc Calcic Lixisol
LXcr Chromic Lixisol
LXfr Ferric Lixisol
LXgl Gleyic Lixisol
LXgr Geric Lixisol
LXha Haplic Lixisol
LXhu Humic Lixisol
LXle Leptic Lixisol
LXll Lamellic Lixisol
LXohh Hyperochric Lixisol
LXpf Profondic Lixisol
LXpl Plinthic Lixisol
LXro Rhodic Lixisol
LXst Stagnic Lixisol
LXvi Vitric Lixisol
LXvt Vetic Lixisol
NT Nitisol
NTal Alic Nitisol
NTan Andic Nitisol
NTau Alumic Nitisol
NTdy Dystric Nitisol
NTeu Eutric Nitisol
NTfl Ferralic Nitisol
NTha Haplic Nitisol
NThu Humic Nitisol
NTmo Mollic Nitisol
NTro Rhodic Nitisol
NTum Umbric Nitisol
NTvt Vetic Nitisol
PH Phaeozem
PHab Albic Phaeozem
PHan Andic Phaeozem
PHap Abruptic Phaeozem
PHca Calcaric Phaeozem
PHcr Chromic Phaeozem
PHgl Gleyic Phaeozem
PHgs Glossic Phaeozem
PHgz Greyic Phaeozem
PHha Haplic Phaeozem
PHle Leptic Phaeozem
PHlv Luvic Phaeozem
PHph Pachic Phaeozem
PHsk Skeletic Phaeozem
PHsl Siltic Phaeozem
PHso Sodic Phaeozem
PHst Stagnic Phaeozem
PHtf Tephric Phaeozem
PHvi Vitric Phaeozem
PHvm Vermic Phaeozem
PHvr Vertic Phaeozem
PL Planosol
PLab Albic Planosol
PLal Alic Planosol
PLar Arenic Planosol
PLau Alumic Planosol
PLax Alcalic Planosol

PLca Calcaric Planosol
PLcc Calcic Planosol
PLcr Chromic Planosol
PLdy Dystric Planosol
PLeu Eutric Planosol
PLfr Ferric Planosol
PLge Gelic Planosol
PLgl Gleyic Planosol
PLgr Geric Planosol
PLgy Gypsic Planosol
PLha Haplic Planosol
PLhi Histic Planosol
PLlv Luvic Planosol
PLmo Mollic Planosol
PLpf? Petroferric Planosol
PLpl Plinthic Planosol
PLro Rhodic Planosol
PLso Sodic Planosol
PLszn Endosalic Planosol
PLti Thionic Planosol
PLum Umbric Planosol
PLvr Vertic Planosol
PT Plinthosol
PTab Albic Plinthosol
PTac Acric Plinthosol
PTal Alic Plinthosol
PTap Abruptic Plinthosol
PTau Alumic Plinthosol
PTdun Endoduric Plinthosol
PTeun Endoeutric Plinthosol
PTfr Ferric Plinthosol
PTgr Geric Plinthosol
PTgs Glossic Plinthosol
PTha Haplic Plinthosol
PThu Humic Plinthosol
PTph Pachic Plinthosol
PTpt Petric Plinthosol
PTst Stagnic Plinthosol
PTum Umbric Plinthosol
PTvt Vetic Plinthosol
PZ Podzol
PZam Anthric Podzol
PZcb Carbic Podzol
PZdn Densic Podzol
PZet Entic Podzol
PZfg Fragic Podzol
PZge Gelic Podzol
PZgl Gleyic Podzol
PZha Haplic Podzol
PZhi Histic Podzol
PZll Lamellic Podzol
PZpi Placic Podzol
PZrs Rustic Podzol
PZsk Skeletic Podzol
PZst Stagnic Podzol
PZum Umbric Podzol
RG Regosol
RGad Aridic Regosol
RGah Anthropic Regosol
RGai Aric Regosol
RGanb Thaptoandic Regosol
RGar Arenic Regosol
RGca Calcaric Regosol
RGdy Dystric Regosol
RGeu Eutric Regosol
RGga Garbic Regosol
RGge Gelic Regosol
RGgl Gleyic Regosol
RGgp Gypsiric Regosol
RGgt Gelistagnic Regosol
RGha Haplic Regosol
RGhu Humic Regosol
RGle Leptic Regosol
RGohh Hyperochric Regosol
RGrd Reductic Regosol
RGsk Skeletic Regosol
RGsow Hyposodic Regosol
RGsp Spolic Regosol
RGst Stagnic Regosol
RGszw Hyposalic Regosol
RGtf Tephric Regosol
RGty Takyric Regosol
RGub Urbic Regosol
RGvib Thaptovitric Regosol
RGvm Vermic Regosol
RGye Yermic Regosol
SC Solonchak
SCad Aridic Solonchak
SCae Aceric Solonchak
SCcc Calcic Solonchak
SCcl Chloridic Solonchak
SCcn Carbonatic Solonchak
SCdu Duric Solonchak
SCge Gelic Solonchak
SCgl Gleyic Solonchak
SCgy Gypsic Solonchak
SCha Haplic Solonchak
SChi Histic Solonchak
SCmo Mollic Solonchak
SCoh Ochric Solonchak
SCps Petrosalic Solonchak
SCso Sodic Solonchak
SCst Stagnic Solonchak
SCsu Sulphatic Solonchak
SCszh Hypersalic Solonchak
SCty Takyric Solonchak
SCvr Vertic Solonchak
SCye Yermic Solonchak
SN Solonetz
SNab Albic Solonetz
SNad Aridic Solonetz
SNcc Calcic Solonetz
SNdu Duric Solonetz
SNgl Gleyic Solonetz

SNgy Gypsic Solonetz
SNha Haplic Solonetz
SNhu Humic Solonetz
SNmg Magnesic Solonetz
SNmo Mollic Solonetz
SNst Stagnic Solonetz
SNsz Salic Solonetz
SNty Takyric Solonetz
SNvr Vertic Solonetz
SNye Yermic Solonetz
UM Umbrisol
UMab Albic Umbrisol
UMam Anthric Umbrisol
UMar Arenic Umbrisol
UMfl Ferralic Umbrisol
UMge Gelic Umbrisol
UMgl Gleyic Umbrisol
UMha Haplic Umbrisol
UMhu Humic Umbrisol
UMle Leptic Umbrisol
UMsk Skeletic Umbrisol
UMst Stagnic Umbrisol
VR Vertisol
VRal Alic Vertisol
VRcc Calcic Vertisol
VRcr Chromic Vertisol
VRdu Duric Vertisol
VReu Eutric Vertisol
VRgm Grumic Vertisol
VRgp Gypsiric Vertisol
VRgy Gypsic Vertisol
VRha Haplic Vertisol
VRms Mesotrophic Vertisol
VRmz Mazic Vertisol
VRna Natric Vertisol
VRpe Pellic Vertisol
VRsow Hyposodic Vertisol
VRsz Salic Vertisol
VRti Thionic Vertisol
11111 Town
22222 Soil disturbed by man
33333 Water body
44444 Marsh
55555 Glacier
66666 Rock outcrops
No information

DR = Depth to rock.
S = Shallow (< 40 cm)
M = Moderate (40 - 80 cm)
D = Deep (80 - 120 cm)
V = Very deep (> 120 cm)

VS = Volume of stones.
00 = 0 % stones
10 = 10 % stones
15 = 15 % stones
20 = 20 % stones

MIN_TOP = Topsoil mineralogy.
KQ = 1/1 Minerals + Quartz
KX = 1/1 Min. + Oxy. & Hydroxy.
MK = 2/1 & 1/1 Minerals
M = 2/1 & 2/1/1 non swel. Min.
MS = Swel. & non swel. 2/1 Min.
S = Swelling 2/1 Minerals
TV = Vitric Minerals
TO = Andic Minerals
NA = Not applicable

MIN_SUB = Subsoil mineralogy.
KQ = 1/1 Minerals + Quartz
KX = 1/1 Min. + Oxy. & Hydroxy.
MK = 2/1 & 1/1 Minerals
M = 2/1 & 2/1/1 non swel. Min.
MS = Swel. & non swel. 2/1 Min.
S = Swelling 2/1 Minerals
TV = Vitric Minerals
TO = Andic Minerals
NA = Not applicable

PD_TOP = Topsoil packing density.
L = Low
M = Medium
H = High

PD_SUB = Subsoil packing density.
L = Low
M = Medium
H = High

SLOPE-DOM: Dominant slope class of the STU

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0 No information
1 Level (dominant slope ranging from 0 to 8 %)
2 Sloping (dominant slope ranging from 8 to 15 %)
3 Moderately steep (dominant slope ranging from 15 to 25 %)
4 Steep (dominant slope over 25 %)

SLOPE-SEC: Secondary Slope class of the STU

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0 No information
1 Level (dominant slope ranging from 0 to 8 %)
2 Sloping (dominant slope ranging from 8 to 15 %)
3 Moderately steep (dominant slope ranging from 15 to 25 %)
4 Steep (dominant slope over 25 %)

IL: Code for the presence of an impermeable layer within the soil profile of the STU

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0 No information
1 No impermeable layer within 150 cm
2 Impermeable layer between 80 and 150 cm
3 Impermeable layer between 40 and 80 cm
4 Impermeable layer within 40 cm

BS_SUB = Base saturation of the subsoil.
H = High (> 50 %)
L = Low (< 50 %)

BS_TOP = Base saturation of the topsoil.
H = High (> 75 %)
M = Medium (50 - 75 %)
L = Low (< 50 %)

PEAT = Peat.
N = No
Y = Yes

OC_TOP = Topsoil organic carbon content.
H = High (> 6 %)
M = Medium (2 - 6 %)
L = Low (1 - 2 %)
V = Very low (< 1 %)

CLIMANR: Code for the grouped climate categories

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1 Northern (climate number: 11, 12, 21, 22, 23, 31, 34, 35)
2 Atlantic (climate number: 32, 41, 42, 43, 431)
3 Sub-atlantic (climate number: 44, 51, 52, 58, 441)
4 Northern sub-continental (climate number: 33, 45, 48, 451, 481)
5 Mediterranean semi-arid (climate number: 46, 47, 461)
6 Southern sub-continental (climate number: 53, 54, 55, 541, 551, 571)
7 Mediterranean (climate number: 56, 57)
8 Temperate mountanous (climate number: 49)

CORGRP_CAT: Code for the grouped CORINE 2006 categories

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210 Agricultural areas (CORINE_06: 211, 212, 213, 241, 242, 243, 244)
220 Vineyard and fruit tree areas (CORINE_06: 221, 222, 223)
230 Meadow, pasture and natural grassland areas (CORINE_06: 231, 321, 322)
310 Forest (wood) areas (CORINE_06: 311, 312, 313)
320 Woody and scrub areas (CORINE_06: 321, 322)
410 Peat bog areas (CORINE_06: 412)

Estimated parameters and rules

1., DISR = Depth to the impermeable rock
S: < 40 cm
M: 40-80 cm
D: 80-120 cm
V: 120 cm <
DISR: ← PARMADO
← PARMASE
← DR

2., DG = Depth to the groundwater
S: 0-80 cm
M: 80-120 cm
D: 120-200 cm
V: 200 cm <
DG: ← WRBFU

3., MDSP = Maximum depth of soil profile with filter and storage properties
S: 0-20 cm
M: 0-60 cm
D: 0-100 cm
V: 0-150 cm
MDSP: ← DISR
← DG

4., MTDCH = Modified depth to a textural change code
0: no textural change
1: 30 cm
2: 40 cm
3: 50 cm
4: 60 cm
5: 70 cm
6: 80 cm
MTDCH: ← TEXTDEPCHG
← MDSP

5., CPT = Clay percentage of the topsoil
0: no information
1: ~ 10 %
2: ~ 20 %
3: ~ 30 %
4: ~ 50 %
5: ~ 80 %
9: ~ peat
CPT: ← TEXTSRFDOM
← TEXTSRFSEC

6., CPS = Clay percentage of the subsoil
0: no information
1: ~ 10 %
2: ~ 20 %
3: ~ 30 %
4: ~ 50 %
5: ~ 80 %
9: ~ peat
CPS: ← TEXTSUBDOM

← TEXTSUBSEC

7., MCPT = Modified clay percentage of the topsoil
0: peat
1: VL (very low)
2: L (low)
3: M (medium)
4: H (high)
5: VH (very high)
MCPT: ← CPT
← VS
← PD_TOP

8., MCPS = Modified clay percentage of the subsoil
0: peat
1: VL (very low)
2: L (low)
3: M (medium)
4: H (high)
5: VH (very high)
MCPT: ← CPS
← VS
← PD_TOP

9., SPCC = Clay content of the soil profile
(1 - 10); 1: low, 10: high
SPCC: ← MCPT
← MCPS
← MDSP
← MTDCH

10., HLT = Thickness of humus layer
1: thin
2: medium
3: thick
HLT: ← WRB_GRP
← MDSP

11., HQ = Humus quality code
F: fulvic acid
H: humic acid
T: peat
HQ: ← WRB_GRP

12., SPHC = Humus content of soil profile
(0 – 5); 1: low, 5: high
SPHC: ← PEAT
← OC_TOP
← CPT
← CPS
← HLT
← VS
← PD_TOP

13., WB = Water balance code
1: no leaching
2: low leaching
3: moderate leaching
4: high leaching
5: very high leaching
WB: ← CLIMANR

14., SLOPEM = Modified slope category
0: no information
1: 0-8 %
2: 8-15 %
3: 15-25 %
4: 25 % <
SLOPEM: ← SLOPE_DOM
← SLOPE_SEC

15., WBM = Modified water balance
0: no information
1: 0-8 %
2: 8-15 %
3: 15-25 %
4: 25 % <
WBM: ← SLOPEM
← CORGRP_CAT
← WB

16., TPD_f = Topsoil packing density factor
1: PD_TOP = L
0,8: PD_TOP = M
0,6: PD_TOP = H
TPD_f: ← PD_TOP

17., SPD_f = Subsoil packing density factor
1: PD_SUB = L
0,9: PD_SUB = M
0,8: PD_SUB = H
SPD_f: ← PD_SUB

18., IL_f = Impermeable layer factor
1: no impermeable layer
0,8: impermeable layer between 80-150 cm
0,6: impermeable layer between 40-80 cm
0,4: impermeable layer within 40 cm
IL_f: ← IL

19., IR = Infiltration rate
(1 – 10); 1: low, 10: high
IR: ← SPCC
← TPD_f
← SPD_f
← IL_f

20., LEACH_f = Leaching factor
1: WBM = 0 or 1
0,9: WBM = 2
0,8: WBM = 3
0,7: WBM = 4
0,6: WBM = 5
LEACH: ← WBM

21., IR_f = Infiltration rate factor
1: IR = 1
0,9: IR = 2
0,85: IR = 3
0,8: IR = 4
0,75: IR = 5
0,7: IR = 6
0,65: IR = 7
0,6: IR = 8
0,55: IR = 9
0,5: IR = 10
IR_f: ← IR

22., CEC_HUM = Cation exchange capacity related to humus content
(1 – 10); 1: low; 10: high
CEC_HUM: ← SPHC
← HQ

23., SSA_HUM = Specific surface area related to humus content
(1 – 10); 1: low; 10: high
SSA_HUM: ← SPHC
← HQ

24., CEC_MIN = Cation exchange capacity related to the soil minerals
(1 – 10); 1: low; 10: high
CEC_MIN: ← SPCC
← MIN_TOP
← MIN_SUB

25., SSA_MIN = Specific surface area related to soil minerals
(1 – 10); 1: low; 10: high
SSA_MIN: ← SPCC
← MIN_TOP
← MIN_SUB

26., CEC_SUM = Cation exchange capacity related to soil minerals and humus content
(1 – 10); 1: low; 10: high
CEC_SUM: ← CEC_MIN
← CEC_HUM

25., SSA_SUM = Specific surface area related to soil minerals and humus content
(1 – 10); 1: low; 10: high
SSA_SUM: ← SSA_MIN
← SSA_HUM

26., BASE_SAT = Base saturation of the soil profile
(1 – 10); 1: low; 10: high
BASE_SAT: ← BS_TOP
← BS_SUB

27., AER = Aeration code
1: DG = S
2: DG = M
3: DG = D
4: DG = V
AER: ← DG

28., CATS_f = Cation sorption factor
(0,1 – 1); 0,1: low; 1: high
CATS_f: ← BASE_SAT
← AER

29., ANS_f = Anion sorption factor
(0,1 – 1); 0,1: low; 1: high
ANS_f: ← BASE_SAT
← AER

30., DG_f = Groundwater depth factor
1: DG = S, M or D
2: DG = V
DG_f: ← DG

31., MIN_f = Mineral factor
1: all minerals, except KX (1/1 Min. + Oxy. & Hydroxy.)
1,5: KX (1/1 Min. + Oxy. & Hydroxy.)

32., STOR_CAPCA = Cation storing capacity (elements in cationic form and organic chemicals with positive charges)
(1-10; 1: poor; 10: good)
STOR_CAPCA: ← CEC_MIN
← CATS_f
← CEC_HUM
← LEACH_f

33., FILT_CAPCA = Cation filtering capacity (elements in cationic form and organic chemicals with positive charges)
(1-10; 1: poor; 10: good)
FILT_CAPCA: ← CEC_MIN
← CATS_f
← CEC_HUM
← IR_f
← DG_f

34., STOR_CAPAN = Anion storing capacity (elements in anionic form and organic chemicals with negative charges)
(1-10; 1: poor; 10: good)
STOR_CAPAN: ← SSA_MIN
← MIN_f
← SSA_HUM
← ANS_f
← LEACH_f

35., FILT_CAPAN = Anion filtering capacity (elements in anionic form and organic chemicals with negative charges) (1-10; 1: poor; 10: good)
FILT_CAPAN: ← SSA_MIN
← SSA_HUM

← ANS_f
← IR_f
← DG_f
← MIN_f

36., STOR_CAPSO = Solids and pathogenic microorganisms storing capacity
(1-10; 1: poor; 10: good)
STOR_CAPSO: ← SSA_SUM
← LEACH_f

37., FILT_CAPSO = Solids and pathogenic microorganisms filtering capacity
(1-10; 1: poor; 10: good)
FILT_CAPSO: ← SSA_SUM
← IR_f
← DG_f

38., STOR_CAPNP = Non-polar organic chemicals storing capacity
(1-10; 1: poor; 10: good)
STOR_CAPNP: ← SSA_SUM
← LEACH_f

39., FILT_CAPNP = Non-polar organic chemicals filtering capacity
(1-10; 1: poor; 10: good)
FILT_CAPNP: ← SSA_SUM
← IR_f
← DG_f

40., STOR_NAPL = Nonaqueous Phase Liquids (NAPL) storing capacity
(1-10; 1: poor; 10: good)
STOR_NAPL: ← SPCC
←SSA_SUM
←LEACH_f

41., FILT_NAPL = Nonaqueous Phase Liquids (NAPL) filtering capacity
(1-10; 1: poor; 10: good)
FILT_NAPL: ← SSA_SUM
← IR_f
←DG_f

List of figures

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